EVALUATION OF SAFETY AT RAILROAD-HIGHWAY GRADE CROSSINGS IN URBAN AREAS

SEPTEMBER 1966

NO. 16

by

W. D. BERG

Joint Highway Research Project

PURDUE UNIVERSITY
LAFAYETTE INDIANA

Final Report

EVALUATION OF SAFETY AT RAILROAD-HIGHWAY GRADE CROSSINGS IN URBAN AREAS

TO: Dr. G. A. Leonards, Director
Joint Highway Research Project

September 20, 1966

FROM: H. L. Michael, Associate Director
Joint Highway Research Project

File: 8-5-9

Project: C-36-59I

The attached Final Report "Evaluation of Safety at Railroad-Highway Grade Crossings in Urban Areas" has been authored by Mr. William D. Berg, Graduate Assistant on our staff. Professor J. C. Oppenlander provided guidance and direction for the research.

This research developed a model which expresses potential hazard as a function of protective device, traffic volume, train volume, effective sight distance and roadside distractions. Methods of selecting a minimum level of grade crossing protection and for establishing priorities of improvement of protection were developed. This research complements previous research on crossings in rural areas previously reported to the Board.

The report is presented to the Board for the record.

Respectfully submitted,

Harold L. Michael/jgs

Harold L. Michael
Associate Director

HLM:jgs

Attachment

Copy:

F. L. Ashbaucher
J. R. Cooper
J. W. Delleur
W. L. Dolch
W. H. Goetz
W. L. Grecco
G. K. Hallock
F. S. Hill
J. F. McLaughlin
F. B. Mendenhall
R. D. Miles
J. C. Oppenlander
W. P. Privette
M. B. Scott
F. W. Stubbs
K. B. Woods
E. J. Yoder

Final Report

Evaluation of Safety at Railroad-Highway Grade Crossings in Urban Areas

by

William D. Berg
Graduate Assistant

Joint Highway Research Project
File No: 8-5-9
Project No: C-36-59I

School of Civil Engineering
Purdue University
Lafayette, Indiana

September 22, 1966

ACKNOWLEDGMENTS

The author wishes to express his sincere appreciation to Prof. Joseph C. Oppenlander for his guidance throughout this research and his critical review of the manuscript; to Prof. William L. Grecco and Prof. Heebok Park for their advice and their reviews of the manuscript; and to Thomas G. Schultz, Walter G. Vodrazka, and Gary M. Jouris for their advice and suggestions.

The author also wishes to acknowledge the assistance of the Indiana State Police, and the fifteen railroad companies which supplied various data.

TABLE OF CONTENTS

TABLE OF CONTENTS (cont'd.)

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Berg, William Douglas. MSCE, Purdue University, January 1967. Evaluation of Safety at Railroad-Highway Grade Crossings in Urban Areas. Major Professor: Joseph C. Oppenlander.

The purpose of this research investigation was to determine the relative effects of those factors which significantly influence the accident patterns at urban railroad-highway grade crossings; to develop mathematical models that measure the relative safety or hazard of urban grade crossings; and to establish a priority rating system, based on the models, for determining protection improvements in urban areas.

The mathematical techniques of discriminant and regression analysis were utilized to develop discriminant models with linearly assigned probabilities. These models permitted potential hazard to be expressed as the probability that a grade crossing is accident prone. A grade crossing where an accident had occurred during a two-year period was considered as a representative member of the population of accident prone crossings. A location which had not experienced an accident for at least five years prior to the date of field investigation was assumed as a representative member of the population of non-accident prone grade crossings. Data were collected at 295 accident locations and 281 non-accident locations in urban portions of the State of Indiana.

The best discriminant model was 74 percent successful in classifying the true group membership of the sample grade crossings. The model expressed potential hazard as a function of protective device, average

daily highway traffic, average daily train traffic, degree of effective sight distance, and roadside distractions. A methodology was developed for selecting a minimum level of grade crossing protection and establishing priorities for the improvement of protection at urban railroad-highway grade crossings.

INTRODUCTION

Railroads and highways are the two primary networks of surface transportation serving the entire nation. Both systems are essential to the public interest. However, exposure to potential collisions between trains and motor vehicles at some 224,000 railroad-highway grade crossings throughout the United States has created a serious problem with regard to the convenience and safety of highway travel (14)*. This problem has grown tremendously during the past few decades because of the rapid growth in vehicle-miles of travel.

Accidents which occur at these crossings, although a numerically small part of the overall highway accident problem, are usually severe and result in a relatively high number of deaths. During the four-year period of 1961 through 1964, nationwide statistics indicated that fatalities due to railroad-highway grade crossing accidents increased 36 percent in rural areas and 20 percent in urban areas (30). In Indiana, the death rate for motor vehicle-train accidents has followed a similar pattern. Between the years 1964 and 1965, Indiana traffic deaths increased seven percent, but deaths resulting from motor vehicle collisions with railroad trains increased by 24 percent. The severity of motor vehicle-train accidents is demonstrated by the fact that the 102 people killed in this type of accident in Indiana during 1965 represented 6.8 percent of the total highway fatalities while motor vehicle-train accidents accounted for only 0.4 percent of the total number of traffic accidents (17).

* Numbers in parentheses refer to articles listed in the Bibliography.

It is usually difficult to assign a particular cause to railroad-highway grade crossing accidents. Rather, numerous influences appear to exist which vary in importance for different combinations of factors. Accidents may be caused by an error in perception, judgment, or action by the motor vehicle driver (8). Such factors as weather conditions, distractions, obstructions, railroad and highway traffic and operational features, geometry of the railroad, roadway, and grade crossing, and type of protective device may be related to the causes of an accident.

Possible solutions to the grade crossing problem have included better enforcement of laws and regulations which apply to motor vehicle drivers at grade crossings, improvement of the level of grade crossing protection, and construction of grade separations. Application of the latter two alternatives by highway and traffic engineers is economically limited. It is estimated that $86 billion would be required to separate all grade crossings in the United States (14). Even the installation of automatic protective devices at all crossings would cost a minimum of $1.8 billion with annual maintenance costs averaging about $200 million per year. The total application of either alternative would not only be prohibitive in cost, but economically unjustified. Based upon engineering principles, a feasible solution is to develop some type of priority rating system for the improvement of the level of grade crossing protection.

Criteria and warrants for protective devices have yet to be developed for application on a rational basis. The general warrants used by Indiana and many other states do not result in priority ratings based on hazard. The priority for improving crossing protection is predicated on subjective judgment. In addition, very little accident research has been directed

toward urban grade crossings. Therefore, further research and analysis is warranted by the possibility of expanding motor vehicle safety at urban grade crossings through the development of a program of protection improvement priorities.

The objectives of this research investigation were:

1. To determine the relative effects of those factors which significantly influence the accident patterns at urban railroad-highway grade crossings.
2. To develop mathematical models that measure the relative safety or hazard of urban grade crossings.
3. To establish a priority rating system, based on the models, for determining protection improvements in urban areas.

The results of this study allow a systematic reduction in hazard at grade crossings in urban areas by the utilization of protection improvement priorities. An insight into the grade crossing problem is offered, as well as an indication of what segment of the problem lies within the working province of the engineer. This investigation also complements the recently completed Joint Highway Research Project study of grade crossings located in the rural portion of Indiana (36). By applying the results of this research, it may be possible to substantially improve the safety of highway travel at railroad-highway grade crossings in urban areas.

REVIEW OF LITERATURE

The first passenger railroad operation in the United States was established in 1830 and consisted of horse-drawn rail cars (10). In that period emphasis was placed on warning the public of the presence of a railroad. Grade crossing protection was provided by placing a conspicuous sign at the crossing, but the sign legends usually lacked uniformity (5). In later years, protection at hazardous crossings consisted of a flagman, using a red flag during the day and a red light at night, to warn of the approach of a train. Manually operated gates gradually replaced the frequently ignored grade crossing flagmen.

In 1872, William Robinson invented the track circuit which permitted the installation of automatic warning systems (10). The first device to be controlled automatically was a warning bell. With subsequent refinement of the track circuit, many different signal designs were developed and used. In 1961, the Interstate Commerce Commission reported that about 19 percent of the approximately 224,000 railroad-highway grade crossings in the United States were equipped with automatic warning devices (18).

Type of Protection

Today there exists an overall uniformity in the design and use of both signs and signals at railroad crossings. Most types of protection have been standardized by the Association of American Railroads and the

National Joint Committee on Uniform Traffic Control Devices (2, 7, 40). The following types of protection are included in these specifications and standards:

1. Painted crossbuck,
2. Reflectorized crossbuck,
3. Flasher,
4. Flasher and bell,
5. Gate and flasher,
6. Gate, flasher, and bell,
7. Manual gate, and
8. Watchman.

The degree of warning offered by grade crossing protective devices can be separated into two basic categories (1). In the case of either a painted or reflectorized crossbuck sign, the driver determines whether or not there are train movements for which he should stop. For automatic signals and gates the driver is given a more positive indication of when to stop. Nevertheless, automatic signals do not completely eliminate the necessity of driver decision. With regard to driver obedience to a signal indicating the approach of a train, the Uniform Vehicle Code states that a driver must stop within 50 ft but not less than 15 ft of the nearest rail when a warning is given or observed, and that the driver shall not proceed until he can do so safely (29). Thus, the final responsibility once again rests with the motor vehicle driver.

An Interstate Commerce Commission investigation of railroad-highway grade crossing accidents, conducted during 1961 and 1962, found that the principal cause of grade crossing accidents was the failure of motor

carrier operators to exercise due caution or to observe and obey safety laws and regulations. It was recommended that prompt action was necessary to enforce safety laws and regulations pertaining to grade crossings (6).

Clearly, public compliance of automatic protective devices is directly related to grade crossing accidents. If all drivers of motor vehicles complied with existing laws and regulations and exercised proper caution at grade crossings, there would be fewer motor vehicle-train collisions. Because it is assumed that automatic protective devices provide adequate warning to drivers, in many cases driver compliance remains as the determining factor (13). The Association of American Railroads has effectively summarized the following predominant factors relating the driver and the protective device:

> In order for grade crossing protective devices to reach their maximum effectiveness the meaning of their aspects must be prescribed, the drivers educated and necessary law enforcement provided. The presence of crossing signals does not in itself insure safe passage over the track. The driver and others must be aware of their obligation to use due caution at such intersections, which includes obedience to the signals (5).

Stop signs have been recommended and incorporated at some railroad-highway grade crossings (21, 28, 32, 43). The application of this device is based on the reasoning that the best protective devices must be signs or signals that drivers are conditioned to obey by reflex. Because the majority of motor vehicle drivers have developed this conditioned response to the stop sign, this traffic control device is often assumed to be a panacea for the grade crossing problem.

Contrary conclusions were observed in a recent study of stop sign protection at railroad-highway grade crossings conducted by the Traffic

Engineering Department of the City of Lincoln, Nebraska. Train speeds, traffic volumes, sight distances, direction of approach, angle of the crossing, number of tracks, and daytime-nighttime conditions did not significantly influence driver reaction at stop signs located at grade crossings. Driver compliance to stop signs at railroad-highway grade crossings was inadequate and it was concluded that such installations encourage willful violations and create contempt and disrespect for all stop signs. Therefore, the investigators recommended that stop signs should not be used as a grade crossing protective device (9).

Protection Coefficients

Protection coefficients are comparative numerical ratings of the measure of protection afforded by various devices. Protection coefficients are usually expressed as a function of either accident rates or reductions in accident rates.

In a 1941 study performed by the Division of Transport, Public Roads Administration, L. E. Peabody and T. B. Dimmick analyzed data on 3,563 rural grade crossings in 29 states for a five-year period (34). Protection coefficients were empirically related to exposure units and accident experience by the following equation:

$$P = \frac{1}{100\ N} \sum_{i=1}^{N} \left(\frac{H \times T}{A}\right)$$

where P = the protection coefficient for a type of protection,

N = the number of crossings in a type group,

H = the average daily traffic volume at each crossing,

T = the average daily train volume at each crossing,

Engineering Department of the City of Lincoln, Nebraska. Train speeds, traffic volumes, [illegible] direction of approach, angle of the crossing, number of [illegible] conditions [illegible]

[illegible]

A = the number of accidents occurring during the five-year period.

The resulting protection coefficients were:

Crossbucks	19
Bells	29
Flashers	96
Flasher and bells	114
Gates	333

C. McEachern studied the accident experience of 190 mainline railroad grade crossings on major thoroughfares in Houston, Texas, for a three-year period (26). The following coefficients were developed and are based on accidents per unit exposure (product of train and traffic volumes):

Crossbucks	0.015
Flashers	0.005
Gates	0.002

W. J. Hedley used the records of the Wabash Railroad for a twenty-year period from 1920 to 1940 to develop coefficients based on accident rates after a change in protection (15). The following coefficients were determined for a sample of 321 grade crossings:

Painted crossbucks	0.504
Reflectorized crossbucks	0.445
Bells	0.394
Flashers - multiple tracks	0.304
Flashers - single track	0.177

Gates	0.093

The Automotive Safety Foundation summarized the results of several reported studies which developed protection coefficients (8). The cross-buck was assigned a reference index of unity. Indices which indicated the number of accidents likely to occur at a crossing with a particular type of protective device in place were developed for other forms of protection. The composite coefficients, with ranges to compensate for various numbers of tracks, are as follows:

Crossbucks	1.0
Flashers	0.3 - 0.6
Gates	0.1 - 0.2

The above protection coefficients indicate the relative effectiveness of various protective devices. Because the experimental conditions varied for each study, any conclusions based on these values should be qualitative in nature.

Accident Prediction Equations

Accident prediction equations are formulated to estimate the number of accidents that might occur at a particular location over a given period of time. Resulting accident frequency predictions have been used in the determination of priorities for the improvement of grade crossing protection (27).

Accident prediction equations are expressed in terms of a relative weighting of various influencing variables. These variables are initially selected on the basis of their possible correlation with accident occurrence. Among those variables included in previous research investigations are:

1. Average daily traffic volume,
2. Average daily train volume,
3. Type of protection,
4. Daylight or darkness,
5. Number of tracks,
6. Train speeds,
7. Vehicle speeds,
8. Type of highway,
9. Geometrics of the crossing (sight distance, crossing alinement, etc.),
10. Pavement width and number of lanes,
11. Type of highway surface,
12. Distractive influences,
13. Visibility,
14. Illumination, and
15. Vehicle and driver characteristics.

An initial study to develop a prediction equation for the number of grade crossing accidents was the previously mentioned investigation by Peabody and Dimmick (34). A correlation analysis was used to develop the following equation:

$$I = 1.28 \frac{H^{0.170} \times T^{0.151}}{P^{0.171}} + K$$

where I = probable number of accidents in a five-year period,

H = average daily highway traffic,

T = number of trains per day,

P = protection coefficient, and

K = special variable to be calculated from data in the report.

In 1948, W. J. Crecink applied the Peabody and Dimmick equation to railroad-highway grade crossings in the State of Mississippi (12). No significant correlation between predicted accidents and actual accident experience could be found. An improved correlation was obtained when sight distance was included in the prediction equation.

The Oregon State Highway Department completed a study concerned with measuring the relative hazards of railroad grade crossings located on state and federal-aid highway systems (33). The majority of the 400 grade crossings considered were located in incorporated areas. Using accident data for the five-year period from 1946 to 1950, accidents were correlated with possible combinations of four influencing variables:

1. Vehicle volume (v),
2. Train volume (t),
3. Darkness factor (d), and
4. Protection factor (p).

The following curvilinear accident prediction curve provided a 0.72 index of correlation:

$$a_2 = 0.40 + 7.53\ (10^{-5})\ V - 8.72\ (10^{-11})\ V^2$$

where a_2 = predicted number of accidents for a five-year period, and

V = vtpd.

To compensate for the effects of possible influencing variables that were not considered, the ratio of actual accidents (a_1) to predicted

accidents (a_2) for a previous five-year period was used as an adjustment factor in the final equation for measuring relative hazard:

$$IH = VA$$

where IH = index of hazard

V = vtpd, and

$A = a_1/a_2$.

The Armour Research Foundation has conducted two grade crossing accident studies for the Association of American Railroads (3, 4). The results of an analysis of 2,291 grade crossings in the State of Iowa were reported in 1958. Regression analysis techniques were utilized to develop risk factors (the expected accident rates at grade crossings over a 16-year period) as a function of type of protection, highway traffic volume, number of tracks, and a measure of visibility. However, the regression model lacked consistancy with accepted a priori assumptions concerning the relationships between the study variables.

The second study performed by the Armour Research Foundation was an investigation of the relationships between accidents and nine grade crossing characteristics at 7,416 locations in the State of Ohio. A regression analysis routine was used to develop models predicting a ten-year expected accident rate. Equations were developed for four separate types of protection: painted crossbucks, reflectorized crossbucks, flashers, and gates. The predictors used in the models were:

1. Average visibility,
2. Highway grade,
3. Rail traffic volume,

4. Rail traffic speed,

5. Highway traffic volume, and

6. Number of tracks and spurs.

It was shown that rail and highway traffic volumes were the only two statistically significant factors occurring in all four models. Only limited explanation of the variability in accident rates could be offered by the significant variables in the regression equations. The multiple coefficients of determination ranged from approximately 0.16 to 0.49. It was concluded that various unmeasured factors, such as driver motivation and behavior, contribute considerably to railroad-highway grade crossing accident patterns.

D. G. Newnan has also developed accident prediction equations in conjunction with an engineering economic analysis of grade crossing protection improvements (31). By analyzing 617 grade crossings on the California state highway system and collecting accident data for an 18-year period, weighted two-year accident rates were linearly related to the following characteristics:

1. Annual ADT,

2. Number of tracks,

3. Weather (visibility),

4. Number of trains,

5. Crossing angle,

6. Approach grade, and

7. Corner visibility.

The use of two-year accident rates rather than a much longer period of time represented a different approach toward accident prediction equations.

Regression models were developed for five types of protection. In several cases, the models yielded statistical relations inconsistant with a priori assumptions. The coefficients of determination indicated that only 23 to 37 percent of the variation in accident rates could be explained by the equations.

Hazard Equations

Hazard equations are very similar to accident prediction equations. Both attempt to express the antithesis of safety as a measure of various factors. Accident prediction equations are concerned with accident rates, while hazard equations relate influencing factors to an established scale.

T. M. Chubb studied and compared eight hazard index equations, or rating systems, in use by various cities, states, and public utility systems (10). By using these equations to develop priority ratings for 25 grade crossings in the City of Los Angeles, only fair agreement was found between the resulting priority lists. Because the hazard equations were subjective functions, the lack of agreement is explainable.

In a recently completed investigation T. G. Schultz analyzed the effects of environment, topography, geometry of the crossing, and highway and rail traffic patterns with respect to rural grade crossing accidents in the State of Indiana (36). The mathematical techniques of factor analysis and regression analysis were used to compare crossings which had experienced an accident during a two-year period, 1962 through 1963, to locations which had not experienced an accident. Twenty-eight variables at 530 locations were factor analyzed and then correlated with accident experience. Each factor represented a simplified explanation of several influencing variables.

The following four factors, each linearly related to a unique group of variables, were significantly correlated with accident experience:

1. Local service road (negative correlation). All variables which described this factor indicated a local access road.

2. Major railroad facility (positive correlation). This factor reflected movement of many trains at relatively high speeds.

3. Secondary highway (positive correlation). The highway type described by this factor served both local and through traffic.

4. Distractions (positive correlation). This factor was described by the roadside development which may distract drivers.

The regression model which functionally relates these factors with grade crossing hazard permitted an explanation of approximately 22 percent of the variability of the dependent variable, occurrence or non-occurrence of an accident during a two-year period.

A separate regression analysis was also performed using the original variables rather than the factors generated in the factor analysis. Accident occurrence was used as a dichotomous measure of relative hazard in the following equation (the multiple coefficient of determination was 0.18):

$$IH = -0.185 + 0.079\,X_1 + 0.021\,X_2 + 0.011\,X_3 + 0.013\,X_4 + 0.024\,X_5$$

where IH = index of hazard,

X_1 = number of track pairs,

X_2 = pavement width in feet,

X_3 = average trains per day,

X_4 = ADT/1000, and

X_5 = sum of distractions (houses, businesses, and advertising signs per one-half mile, both sides of roadway, for one approach to the crossing).

Type of protection (painted crossbuck, reflectorized crossbuck, flasher, or gate) was not found to be a statistically significant predictor of hazard in the regression model. Although the protective device variables could be eliminated from the hazard equation, this did not warrant the conclusion that protective devices have no influence on reducing hazard. This finding was restricted by a limited variability of the field conditions for the four types of protection investigated. The nomograph shown as Figure 1 was developed for the above regression model. The calculated midpoints between the mean indices of hazard for the three types of protection represent the range of relative hazard for which a given type of protection is warranted to conform with current practice of establishing protection in Indiana.

Warrants and Priority Rating Systems

Limited funds are available for expenditure toward reducing the hazard at railroad-highway grade crossings. Because of the large number of grade crossings and the high cost of modern protective devices, provision of the maximum protection at every location is not always possible. There is general agreement that a need exists for a priority rating system which would indicate both relative hazard, and the minimum level of protection necessary to reduce this hazard effectively.

Numerical warrants and criteria for type of protection at grade crossings have been developed and used by many different agencies. However, no universally acceptable criteria have been adopted for evaluating hazard or for specifying the minimum required level of protection.

Judgment values assigned to various selected influencing factors have resulted in distorted ratings from one locality to another. Many

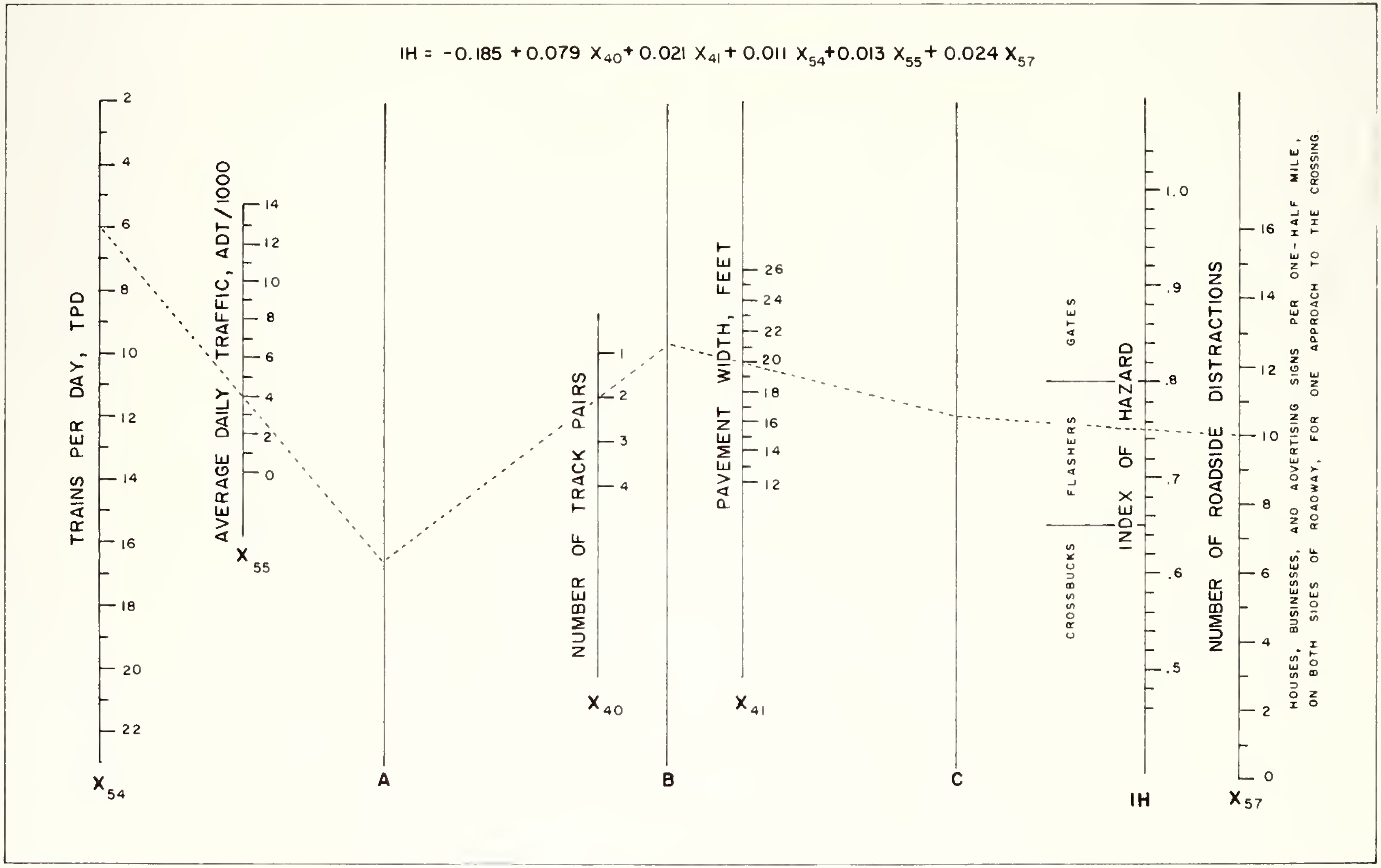


FIGURE I. PROTECTION NOMOGRAPH – GRADE CROSSINGS LOCATED IN RURAL AREAS OF INDIANA

(SOURCE: T.G. SCHULTZ, "EVALUATION OF SAFETY AT RAILROAD-HIGHWAY GRADE CROSSINGS," PURDUE UNIVERSITY, 1965)

states rely on subjective judgment rather than a type of numerical rating (27).

The development of economic warrants has frequently been proposed (25, 27, 31). The suggested procedure usually is to evaluate whether or not a grade crossing has a minimum level of protection consistent with existing conditions. Then by numerically assessing the possible alternatives with respect to both accident potential and installation and operational requirements, select the alternative with the greatest economic justification. This approach is limited by the inadequate techniques available for estimating the true economic value of safety.

PROCEDURE

The first step in this research investigation was the development of a conceptual model of the problem. Previous railroad-highway grade crossing accident studies had defined safety in terms of the frequency of accident occurrence during a given period of time. Grade crossing hazard was considered directly related to the accident rate. This approach required data for a ten- to twenty-year period because of the low frequency of accidents at any single grade crossing. When long-period accident rates were used, the rates exhibited only limited variability. In addition, selected influencing variables which described physical characteristics of the crossings were subject to change during the long-term period under investigation.

Because previous research investigations had achieved only a limited degree of success in predicting grade crossing accident rates, a new approach to the problem appeared to be warranted. The hypothesis assumed in this study was that railroad-highway grade crossings can be classified as either accident prone or non-accident prone. If an accident was experienced during an arbitrary period of time, a grade crossing was considered as a representative member of the accident prone group. If a crossing did not experience an accident, it was classified as a representative member of the non-accident prone group. This approach permitted safety or, conversely, hazard to be assessed in terms of a dichotomous variable representing membership in either the accident prone or non-accident

prone group. Thus, a shorter and more convenient time period was selected for investigation, and the problem of the infrequency of grade crossing accidents at any single location was reduced. In addition, the physical features at any single grade crossing exhibited little variation during the period under investigation.

A two-year period, 1963 through 1964, was selected for investigation, and the study was limited to those railroad-highway grade crossings located within incorporated areas in the State of Indiana. For the purposes of this investigation, hazard was defined as the probability of membership in the accident prone group expressed as a function of various characteristics of the grade crossing.

Description of the Variables

A review of previous investigations provided an initial source of influencing variables. A large number of variables were selected for analysis to minimize the possibility of overlooking any statistically significant hazard predictors. Only those variables which can be evaluated realistically were retained for field investigation. Many variables are identified by a dichotomous measure, 0 or 1, representing absence or presence of a situation.

A summary of the study variables is listed below. Each variable name is followed by the units of its measurement.

Accident Data (Accident Locations Only)

1. Driver age - years.
2. Driver sex (0 if female, 1 if male).
3. Out-of-town driver (0 if in-town, 1 if out-of-town).

4. Out-of-county driver (0 if in-county, 1 if out-of-county).
5. Out-of-state driver (0 if in-state, 1 if out-of-state).
6. Drinking driver (0 if not drinking, 1 if drinking).
7. Vehicle type (0 if truck, 1 if car).
8. Vehicle age - years.
9. Vehicle defects (0 if no defects, 1 if defects were indicated in the accident report).
10. Fatality (0 if no fatality, 1 if fatality).
11. Personal injury (0 if no personal injury, 1 if personal injury) - a fatility was not considered a personal injury for this variable.
12. Property damage loss - dollars/100.
13. Car speed - mph.
14. Speeding driver (0 if not speeding, 1 if speeding).
15. Train speed - mph.
16. Wet pavement (0 if dry, 1 if wet).
17. Ice or snow (0 if pavement was dry, 1 if covered with ice or snow).
18. Vehicle out of control (0 if under control, 1 if out of control) - a skidding vehicle was considered out of control.
19. Darkness (0 if daylight, 1 if darkness) - dawn and dusk were coded as darkness.
20. Clear weather (0 if precipitating, 1 if clear).
21. Stalled vehicle (0 if not stalled, 1 if stalled).
22. Unaware driver (0 if driver was aware of automatic warning signals or train, 1 if not aware).

23. Disregarded warning (0 if driver complied with automatic warning signals, 1 if disregarded).

24. Year of accident (3 if 1963, 4 if 1964).

Field Data (All Locations)

Variables 25 to 39, 41 to 43, 45 to 53, 56 to 59, 62 to 67, and 80 to 84 were coded as 0 if not existing, 1 if existing.

25. Painted crossbuck - good condition.

26. Painted crossbuck - poor condition.

27. Reflectorized crossbuck - good condition.

28. Reflectorized crossbuck - poor condition.

29. Warning bell and crossbuck.

30. Warning bell, crossbuck, and stop sign.

31. Flasher.

32. Flasher and warning bell.

33. Gate and flasher.

34. Gate, flasher, and warning bell.

35. Manual gate.

36. Flagman.

37. Stop sign.

38. Traffic signal coordinated with train movements.

39. No protection.

40. Speed limit - mph.

41. Railroad advance warning sign.

42. Railroad pavement marking.

43. Two-way street.

44. Number of lanes.

45. Local street classification.

46. Collector street classification.

47. Arterial street classification.

48. Painted center line.

49. Curb and gutter.

50. Curb parking.

51. Bus stop - this variable represented bus loading zones adjacent to a grade crossing.

52. Traffic signal - this variable was restricted to traffic signals located within 200 ft of the grade crossing.

53. Illuminated roadway.

54. Pavement width - feet.

55. Average lane width - feet.

56. Portland cement concrete pavement.

57. Asphalt pavement.

58. Brick pavement.

59. Gravel pavement.

60. Number of tracks.

61. Number of mainline tracks.

62. Rough crossing - judgment was based on a test drive, and field observation of driver reactions while traversing the crossing.

63. Railroad yards.

64. Passenger station.

65. Illuminated crossing.

66. Tracks located parallel to the centerline and within the pavement of the roadway.

67. Grade - judgment was used to evaluate this dichotomous variable.
68. Number of businesses on the approach - this variable represented the number of business establishments and all other non-residential structures which were located a distance of 500 ft along the approach to the crossing on both sides of the roadway.
69. Number of advertising signs on the approach - this variable included all signs capable of being read by a motorist and located along the roadway section described for variable No. 68.
70. Number of dwellings on the approach - measured similarly to variable No. 68.
71. Number of access points on the approach - measured similarly to variable No. 68. This variable represented all intersecting streets, alleys, driveways, and business entrances.
72. Number of intersecting streets on the approach - measured similarly to variable No. 68.
73. Number of loading zones on the approach - measured similarly to variable No. 68. This variable represented the number of curb loading zones as well as off-street loading docks or loading facilities visible to a motorist.
74. Number of businesses beyond the crossing - measured similarly to variable No. 68 except that the roadway under consideration was the section extending 200 ft beyond the grade crossing relative to the approach direction.
75. Number of advertising signs beyond the crossing - measured similarly to variable No. 74.

76. Number of dwellings beyond the crossing - measured similarly to variable No. 74.

77. Number of access points beyond the crossing - measured similarly to variable No. 74.

78. Number of intersecting streets beyond the crossing - measured similarly to variable No. 74.

79. Number of loading zones beyond the crossing - measured similarly to variable No. 74.

80. Residential locality.

81. Commercial locality.

82. Industrial locality.

83. Minor obstruction - this variable represented objects such as brush, trees, or temporary obstructions which would obscure the view of an approaching train.

84. Adjacent high volume intersection - this variable represented the existence of a high volume roadway adjacent and parallel to the railroad right-of-way.

85. Population - measured in thousands. This variable represented the population of the incorporated urban area where a grade crossing was located.

86. Angle of intersection - degrees.

87. Line of sight - this variable represented the ratio of the actual corner sight angle to the minimum desirable corner sight angle. The actual corner sight angle was defined as the angle at which a motorist can first view an approaching train when the vehicle is at a distance from the crossing equal to the stopping sight

distance (as determined by the posted speed limit of the roadway). The minimum desirable corner sight angle was defined as the minimum angle (measured at the same location described above) at which a motorist can first view the fastest approaching train and bring his vehicle to a stop in advance of the tracks before the train (traveling at a constant speed) reached the crossing. A mathematical derivation of this variable is presented in Appendix A.

88. Traffic volume - ADT.

Railroad Data (All Locations)

89. Average passenger train speed - mph.
90. Average freight train speed - mph.
91. Average switching movement speed - mph.
92. Average train speed - mph.
93. Average number of passenger trains per day.
94. Average number of freight trains per day.
95. Average number of switching movements per day.
96. Average number of trains per day - TPD.
97. Percentage of non-scheduled trains per day - this variable expressed the number of switching movements per day as a percent of TPD.
98. Speed of fastest train - mph.

Data Collection

Indiana State Police traffic accident reports for the years 1963 and 1964 were used as the data source for all accident variables. Data were

obtained for 295 grade crossing accidents which occurred in urban areas during the two-year period.

For statistical purposes it was desirable to select an approximately equal number of grade crossings representative of the non-accident group. The 281 non-accident locations were randomly chosen in the following manner:

1. The railroad track mileage in each incorporated area in the State of Indiana was measured on a county map.
2. The scaled mileages were recorded and summed.
3. Using random number tables, 281 numbers were selected from the numerical range of the cumulative scaled mileage.
4. Each number represented a non-accident location to be investigated in a specific urban area.
5. The grade crossings in each designated urban area were assigned consecutive numbers.
6. Using random number tables, the required number of grade crossings in each urban area were then selected from the numerically ordered crossings for that area.

To reduce the possibility that a selected non-accident grade crossing was not a representative member of the non-accident prone group, it was specified that the location must not have experienced a vehicle-train accident for a minimum of five years prior to the date of field investigation. To ascertain if the above requirement was fulfilled, the local police department, railroad agencies, and nearest available residents to the crossing were questioned with respect to each proposed location. If an accident had occurred, the site was rejected, and a different grade crossing was randomly selected as a replacement.

The field data collection was performed during the summer months of 1965. Each grade crossing selected for investigation actually represented four possible collision paths between motor vehicles and trains. As a result, data were recorded for a single quadrant representing unique vehicle and train approach directions. At the accident locations the selected quadrant was the one in which the accident occurred. Quadrants at the non-accident locations were selected with respect to a repetitive ordering of geographically designated quadrants (NE, SE, SW, NW, NE, etc).

All field data were recorded on a data sheet shown as Figure 13, Appendix B. The average daily traffic, ADT, was obtained from an 1-hr manual count by means of the traffic volume expansion factors in Table 8 and by daily and monthly traffic volume adjustment factors in Tables 9 and 10, respectively, Appendix C (42). A geologist's compass was used to measure the corner sight angle and the intersection angle. Pavement widths were obtained with a 50-ft cloth tape.

Railroad data were secured by correspondence with railroad companies which operate trains over the crossings.

Analysis of the Data

The collected data were transferred to eighty-column coding sheets. Average train speeds and volumes, as well as the line of sight ratio, were calculated by an electronic computer. The facilities of the Purdue University Computer Sciences Center were then used to punch and verify the complete set of data.

A correlation analysis program was used to develop sums, means, standard deviations, and correlation coefficients for the study variables.

The computer program also permitted combinations of variables to be transgenerated into the following new variables:

99. Painted crossbuck - sum of variable No. 25 and 26.
100. Reflectorized crossbuck - sum of variable No. 27 and 28.
101. Flasher - sum of variable No. 31 and 32.
102. Gate - sum of variable No. 33, 34, and 35.
103. Number of businesses - sum of variable No. 68 and 74.
104. Number of businesses and advertising signs - sum of variable No. 69, 75, and 103.
105. Number of businesses, advertising signs, and dwellings - sum of variable No. 70, 76, and 104.
106. Number of businesses, advertising signs, dwellings, and access points - sum of variable No. 71, 77, and 105.
107. Number of businesses, advertising signs, dwellings, and intersecting streets - sum of variable No. 72, 78, and 105.
108. Number of businesses, advertising signs, dwellings, access points, and loading zones - sum of variable No. 73, 79, and 106.
109. Exposure rate (ADT x TPD) - product of variable No. 88 and 96.

Highly associated variables were examined, and the variables judged to be the less applicable parameter of a given grade crossing characteristic were eliminated. Means and standard deviations aided in the deletion of those variables which were observed at only a very small percentage of the sample locations. Summary statistics were then tabulated from the computer program output of the correlation analysis.

Hazard was previously defined as being a problem of binary assignment; that is, a selected grade crossing was classified as a member of either the accident prone or non-accident prone group. Both groups were assumed to be characterized by a unique distribution of influencing variables. The purpose was to discriminate between the two groups with a minimum chance of misclassification.

Discriminant analysis techniques, which have been applied to the choice of mode problem in urban transportation planning, were conveniently adapted to the analysis of grade crossing hazard (37, 41). By formulating a linear discriminant model of important explanatory variables, a statistical rule was available to indicate those discriminant scores, or hazard values, for which a given location can be classified as either accident prone or non-accident prone.

The linear discriminant model was initially defined as:

$$F = a_o + \sum_{i=1}^{n} a_i X_i$$

where F = discriminant score,

X_i = an explanatory variable,

a_o = constant,

a_i = constant coefficient, and

n = the number of explanatory variables.

For the discriminant model to be useful, it was necessary to choose coefficients which maximized the separation between the density functions representing expected discriminant scores for the accident prone and non-accident prone groups. However, the above model was restricted to the

prediction of a dichotomous classification. It was not statistically possible to distinguish the relative association with either of the two groups. To indicate the change in likelihood of association with either group, linear probabilities were assigned to the above discriminant model under the following constraints:

$$\Pr[\text{observation is from accident prone group}] = \begin{cases} 0, \text{ if } F < 0, \\ F, \text{ if } 0 \leq F \leq 1, \text{ and} \\ 1, \text{ if } 1 < F. \end{cases}$$

The linear relationship was selected because of its mathematical simplicity and its reasonable description of the sample data. This technique permitted the discrimination of hazard to be expressed as a continuous, rather than dichotomous, function of the explanatory variables.

The coefficients of the discriminant model which satisfied the above constraints were obtained by minimizing the expression:

$$G = \sum_{j=1}^{m} (F_j - Y_j)^2$$

where $F_j = a_o + \sum_{i=1}^{n} a_i X_{ij}$,

$Y_j = 1$, if observation is from accident prone group, and

$Y_j = 0$, if observation is from non-accident prone group, and

m = number of sample observations.

This operation maximized the separation of the average discriminant scores for the two groups relative to the variation of the actual discriminant scores within each group. The mechanical procedures of regression analysis provided a convenient method of solving the minimization problem. Thus, potential hazard was expressed as the probability of being classified

as a member of the population of accident prone grade crossings. The success of the discriminant model was defined as the ability to correctly assign group membership. This success was determined by applying the model to the study sample and then computing the percentage of correct classifications of the accident and non-accident grade crossings relative to a classification criterion of 50-percent probability of membership in the accident prone group.

As a check on the appropriateness of the linear assignment of probabilities, the sample locations were separated into ranges of similar discriminant scores. The proportion in each range whose true value belonged to the accident prone group was graphically compared to the linear probability curve described by the discriminant model. This comparison permitted a visual verification of the linear assignment of probabilities.

A methodology, based on the selection of a maximum tolerable accident prone probability, was developed to determine a minimum level of grade crossing protection. Maximum tolerable probability levels were related to the errors resulting from misclassification and to the success of the discriminant model. The misclassification errors expressed the likelihood of overprotection or underprotection. Overprotection was defined as the probability that a non-accident prone grade crossing will be classified as a member of the accident prone group. Similarly, underprotection was defined as the probability that an accident prone grade crossing will be classified as a member of the non-accident prone group. The error probabilities were computed by assigning the sample observations to accident and non-accident prone groups and then determining the proportion of misclassifications in each group. The errors were functionally expressed as:

$$A = \frac{M_a}{N_n}$$

and,

$$B = \frac{M_n}{N_a}$$

where A = probability of underprotection,

B = probability of overprotection,

M_a = number of accident locations which were assigned to the non-accident prone group,

M_n = number of non-accident locations which were assigned to the accident prone group,

N_a = total number of grade crossings assigned to the accident prone group, and

N_n = total number of grade crossings assigned to the non-accident prone group.

An approximate relation between the errors and the percentage of success was as follows:

$$C \approx \frac{(1 - A) + (1 - B)}{2}$$

where C = success percentage of the discriminant model.

This approximate relation simply expresses the average of the two different success rates.

A chart was then developed to permit the selection of a maximum tolerable accident prone probability based on the error of underprotection. This chart was constructed by computing the probability of underprotection associated with various accident prone probability levels. Each probability level represented a different criterion for assigning the group membership of the sample data.

Compliance Study

To provide an additional insight into the effectiveness of grade crossing protective devices, a compliance study was performed at existing flasher and gate installations. Drivers at numerous grade crossings were observed from the engine of a moving train. The survey considered only those motorists who were confronted with a choice of observing or disregarding an actuated signal. If a vehicle was already stopped at the crossing, all other vehicles approaching in that lane were excluded from the study.

RESULTS

The results of this research investigation are presented and discussed relative to the various statistical and engineering analyses performed. The variable number designation used in the PROCEDURE was retained for convenient referencing.

Because there were incomplete data for 40 study locations, the available sample population totaled 536 grade crossings, of which 281 experienced an accident during 1963 or 1964. The remaining 255 crossings did not experience an accident for at least five years prior to the date of field investigation. Means and standard deviations of the study variables are tabulated in Table 11, Appendix D.

Summary Statistics

The correlation analysis provided descriptive statistics of the study grade crossings located in urban areas throughout the State of Indiana. The statistics listed in Table 1 were developed from accident report data for the 281 accident locations. A comparison was made with similar data obtained in the previously referenced study of grade crossings located in the rural portions of Indiana (36).

Several predominant patterns were observed when urban and rural grade crossing accidents were analyzed with respect to the above statistics. Male drivers were involved in most of the grade crossing accidents, while the percentage of female drivers who had accidents was greater in urban

TABLE 1

CHARACTERISTICS OF SAMPLED RAILROAD-HIGHWAY GRADE CROSSING ACCIDENTS

Variable	Urban Locations	Rural Locations
1. Driver		
a. Average driver age	37 yr	36 yr
b. Drivers who were male	78 %	86 %
c. Drivers who resided in the city in which the accident occurred	65 %	-
d. Drivers who resided in the county in which the accident occurred	85 %	72 %
e. Drivers who resided in the State of Indiana	96 %	94 %
f. Accident reports which indicated the driver had been drinking	11 %	6 %
g. Accidents in which the driver apparently was unaware of the train or an automatic warning signal	38 %	-
h. Accidents in which the driver apparently disregarded an automatic warning signal or a flagman	27 %	-
i. Accidents which resulted in at least one personal injury	39 %	48 %
j. Accidents which resulted in at least one fatality	10 %	14 %

TABLE 1 (cont'd.)

Variable	Urban Locations	Rural Locations
k. Average property damage loss	$871	-
2. Vehicle		
a. Trucks	12 %	27 %
b. Average vehicle age	5.1 yr	5.2 yr
c. Accidents in which the vehicle skidded or was out of control	21 %	-
d. Vehicles which evidenced contributing mechanical defects	3 %	17 %
3. Environmental		
a. Accidents which occurred during clear weather	76 %	74 %
b. Accidents which occurred during the hours of darkness	45 %	36 %
c. Pavement surface condition		
1) Dry	60 %	57 %
2) Wet	20 %	16 %
3) Covered with ice or snow	20 %	27 %

areas than in rural areas. Most grade crossing accidents occurred within the city or county in which a motorist resided. Each of these facts can be attributed to driver exposure; that is, most drivers in both urban and rural areas are male, and the percentage of female motorists is greater in urban areas than in rural areas. In addition, most vehicle trips are made within close proximity of the driver's place of residence.

Drinking drivers were more frequently involved in motor vehicle-train accidents in urban areas than in rural areas. This may be a result of the greater number of taverns and bars in urban areas.

In approximately 65 percent of the urban accidents, drivers apparently were unaware of the presence of a train or willfully disregarded an automatic warning device. The high severity of all grade crossing accidents was shown by the fact that a fatality or personal injury occurred in 62 percent of the rural accidents and 49 percent of the urban accidents. This difference in severity was probably due to higher train and vehicle speeds in the rural areas.

The percentage of trucks involved in grade crossing accidents was more than twice as high in rural areas than in urban areas. This result can be attributed to the higher percentage of trucks traveling on rural highways. Contributing mechanical defects in a motor vehicle were more frequent in rural accidents, although the average vehicle age was almost identical for each group.

The importance of environmental conditions was quite apparent. Although approximately 25 percent of the accidents occurred during some form of precipitation, about 40 percent took place on a pavement that was wet or covered with ice or snow. Also, there was a higher frequency of

grade crossing accidents during the period from dusk till dawn when vehicle and train volumes are usually low. Both of these facts indicate the influence of poor visibility.

The data presented as Table 2 represent a summary of the physical features and characteristics of the accident and non-accident grade crossings investigated in this study. The summary includes all variables selected for consideration in subsequent analyses. The frequency of an occurrence is represented by a percentage, and all other measures represent means. The number within the parentheses following each variable name corresponds to the previously listed variable number designation.

Discriminant Analysis

The analysis of grade crossing hazard was restricted to locations protected by a painted crossbuck, reflectorized crossbuck, flasher, or gate. This sample population consisted of 243 accident locations and 222 non-accident locations, or a total sample size of 465 grade crossings.

Development of the Discriminant Model

Several discriminant models with linearly assigned probabilities were developed by the mechanics of regression analysis. These models were formulated for various combinations of explanatory variables to obtain the most successful discriminant model capable of being evaluated from measurements that are readily and conveniently available to the engineer. The success of each model was assessed by determining the percentage of correct classifications for the sampled grade crossings. The basic classification criterion was a discriminant score equivalent to the 50-percent probability of membership in the accident prone group. A

TABLE 2

COMPARISON OF SAMPLED RAILROAD-HIGHWAY GRADE CROSSING CHARACTERISTICS

Variable	Urban Locations		Rural Locations	
	Accident	Non-Accident	Accident	Non-Accident
1. Protective device				
a. Painted crossbuck (99)	20 %	19 %	53 %	69 %
b. Reflectorized crossbuck (100)	11 %	11 %	23 %	20 %
c. Flasher (101)	48 %	44 %	18 %	9 %
d. Gate (102)	8 %	15 %	4 %	1 %
2. Roadway characteristics				
a. Speed limit (40)	27 mph	26 mph	-	-
b. Railroad advance warning sign (41)	21 %	21 %	69 %	72 %
c. Railroad pavement marking (42)	5 %	6 %	10 %	4 %
d. Number of lanes (44)	2.3	2.1	-	-
e. Painted center line (48)	47 %	24 %	-	-
f. Curb and gutter (49)	58 %	47 %	-	-
g. Curb parking (50)	56 %	67 %	-	-
h. Traffic signal within 200 ft of crossing (52)	7 %	1 %	-	-

TABLE 2 (cont'd.)

Variable	Urban Locations Accident	Urban Locations Non-Accident	Rural Locations Accident	Rural Locations Non-Accident
i. Illuminated roadway (53)	19 %	7 %	-	-
j. Pavement width (54)	32 ft	27 ft	20 ft	17 ft
k. Pavement type:				
1) Portland cement concrete (56)	14 %	9 %	7 %	1 %
2) Asphalt (57)	83 %	86 %	75 %	43 %
3) Brick (58)	1 %	3 %	-	-
4) Gravel (59)	2 %	2 %	18 %	56 %
l. Local classification (45)	31 %	60 %	-	-
m. Collector classification (46)	43 %	28 %	-	-
n. Arterial classification (47)	26 %	12 %	-	-
3. Roadside characteristic				
a. Residential locality (80)	30 %	57 %	-	-
b. Commercial locality (81)	36 %	28 %	-	-
c. Industrial locality (82)	34 %	15 %	-	-
d. Minor obstruction (83)	49 %	41 %	70 %	77 %
e. Adjacent high volume intersection (84)	10 %	3 %	-	-

TABLE 2 (cont'd.)

Variable	Urban Locations		Rural Locations	
	Accident	Non-Accident	Accident	Non-Accident
f. Number of businesses (103)	5.0	3.1	1.6*	0.8*
g. Number of advertising signs (69, 75)	4.8	2.5	0.6*	0.1*
h. Number of dwellings (70, 76)	5.5	7.9	3.1*	1.9*
i. Number of access points (71, 77)	8.5	8.6	-	-
j. Number of streets (72, 78)	2.2	2.6	-	-
k. Number of loading zones (73, 79)	0.8	0.6	-	-
4. Railroad crossing characteristic				
a. Number of tracks (60)	2.4	2.0	1.4	1.2
b. Number of main-line tracks (61)	1.4	1.3	-	-
c. Rough crossing (62)	58 %	67 %	-	-
d. Railroad yards (63)	16 %	4 %	-	-
e. Passenger station (64)	4 %	4 %	-	-
f. Illuminated crossing (65)	3 %	2 %	-	-
g. Tracks located parallel to center line and within the pavement of a roadway (66)	5 %	5 %	-	-

TABLE 2 (cont'd.)

Variable	Urban Locations		Rural Locations	
	Accident	Non-Accident	Accident	Non-Accident
h. Grade (67)	10 %	7 %	-	-
i. Angle of intersection (86)	93 deg	89 deg	94 deg	90 deg
j. Line of sight ratio (87)	1.19	1.25	-	-
5. Traffic characteristic				
a. Average daily traffic (88)	4,861	2,299	1,185	342
b. Average passenger train speed (89)	18 mph	16 mph	44 mph	41 mph
c. Average freight train speed (90)	23 mph	25 mph	40 mph	39 mph
d. Average switching movement speed (91)	6 mph	5 mph	-	-
e. Average passenger trains per day (93)	3.4	2.6	2.9	1.8
f. Average freight trains per day (94)	11.0	8.0	9.8	7.0
g. Average switching movements per day (95)	10.0	2.9	-	-
h. Average train speed (92)	21 mph	24 mph	41 mph	39 mph
i. Average trains per day (96)	24.3	13.4	12.7	8.8

TABLE 2 (cont'd.)

Variable	Urban Locations		Rural Locations	
	Accident	Non-Accident	Accident	Non-Accident
j. Average speed of fastest trains (98)	27 mph	28 mph	-	-
k. Percentage of non-scheduled trains per day (97)	35 %	26 %	-	-
l. Exposure rate (109)	132.7	28.0	-	-

* Measured along one-half mile, both sides of roadway, for one approach to the crossing.

probability greater than 50 percent was indicative of a location that was likely to be a member of the accident prone group. A probability less than 50 percent represented a greater likelihood of membership in the non-accident prone group.

The most practical and successful discriminant model was:

$$F = 0.41227 - 0.03276\, X_{87} + 0.02384\, X_{88} + 0.00728\, X_{96}$$
$$- 0.02109\, X_{100} - 0.19494\, X_{101} - 0.52512\, X_{102} + 0.01281\, X_{104}$$

where F = discriminant score,

X_{87} = line of sight ratio,

X_{88} = ADT/1000,

X_{96} = TPD,

X_{100} = presence of a reflectorized crossbuck (0, 1),

X_{101} = presence of a flasher (0, 1),

X_{102} = presence of a gate (0, 1), and

X_{104} = sum of distractions (number of businesses and advertising signs, on both sides of the roadway, along a section extending 500 ft from the crossing to 200 ft beyond the crossing for one approach direction).

Potential hazard, or the probability of membership in the accident prone group, was related to the discriminant model under the following constraints:

$$\Pr[\text{observation is from accident prone group}] = \begin{cases} 0, & \text{if } F < 0, \\ F, & \text{if } 0 \le F \le 1, \\ 1, & \text{if } 1 < F, \text{ and} \end{cases}$$

where F = discriminant score.

This model was 74 percent successful in discriminating between the accident and non-accident grade crossings in the study sample. A more

extensive summary of the ability of the discriminant model to correctly classify group membership is given in Table 3. Success percentages are listed in this table for accident, non-accident, and combined locations grouped by types of protective device.

The explanatory variables appearing in the discriminant model represent easily measured predictors of grade crossing characteristics. The line of sight ratio is a function of maximum actual train speed, angle of intersection, speed limit of the roadway, and the actual corner sight angle. Curves shown as Figures 7 through 12, Appendix A, permit a graphical solution for the line of sight ratio variable. The average daily traffic and the average trains per day variables are measures of relative exposure to potential collisions. The sum of distractions measures the number of possible roadside distractions along the roadway on both sides of the crossing. The four types of protective devices are included in the discriminant model. To calculate the potential hazard at a location with a given type of protection, the remaining protection variables are assigned a value of zero. Because the painted crossbuck represents the lowest form of protective device, only the remaining three protective devices appear as variables in the model.

The relative effectiveness of each type of protective device is indicated by the magnitude of the respective variable coefficients appearing in the discriminant model. These coefficients, as shown in Table 4, represent the reduction in potential hazard (probability of membership in the accident prone group) for a particular type of protective device. The hazard reductions were expressed relative to the level of protection offered by the painted crossbuck. As evidenced by the coefficients, the

TABLE 3

SUCCESS PERCENTAGES FOR THE DISCRIMINANT MODEL WITH LINEARLY ASSIGNED PROBABILITIES

Protective Device	Non-Accident Locations	Accident Locations	Combined Locations
Painted crossbuck	70 %	77 %	74 %
Reflectorized crossbuck	82 %	66 %	73 %
Flasher	80 %	69 %	74 %
Gate	87 %	55 %	75 %
All protective devices	79 %	69 %	74 %

TABLE 4

RAILROAD-HIGHWAY GRADE CROSSING
PROTECTION COEFFICIENTS

Protective Device	Relative Protection
Painted crossbuck	0.000
Reflectorized crossbuck	0.021
Flasher	0.195
Gate	0.525

reflectorized crossbuck offers a very small improvement over the painted crossbuck. This improvement is probably due to the benefits of reflectorization realized during the hours of darkness. However, the automatic flasher is almost ten times more effective than the reflectorized crossbuck, while gate protection is approximately 2.5 times more effective than flasher protection.

Appropriateness of the Discriminant Model

As a check on the appropriateness of the discriminant model with linearly assigned probabilities, the function was graphically compared with actual probabilities of group membership for the sample data. The study sites were divided into ranges of similar discriminant scores. The proportion in each range whose true value belonged to the accident group represented the actual probability of membership in the accident prone group. The graph of the linear discriminant model and the points representing the computed actual probabilities for the sample grade crossings are illustrated in Figure 2. The relatively close scatter of points about the line indicates that the discriminant model with linearly assigned probabilities can offer a reasonable estimate of potential hazard.

Criteria for Minimum Levels of Protection

If the potential hazard at a specific grade crossing can be defined as the probability of its membership in the accident prone group, criteria can be established for judging the minimum level of grade crossing protection. This procedure involves the specification of a maximum tolerable accident prone probability for railroad-highway grade crossings. The minimum level of protection is then defined as the lowest level of protection yielding a probability less than the tolerable value.

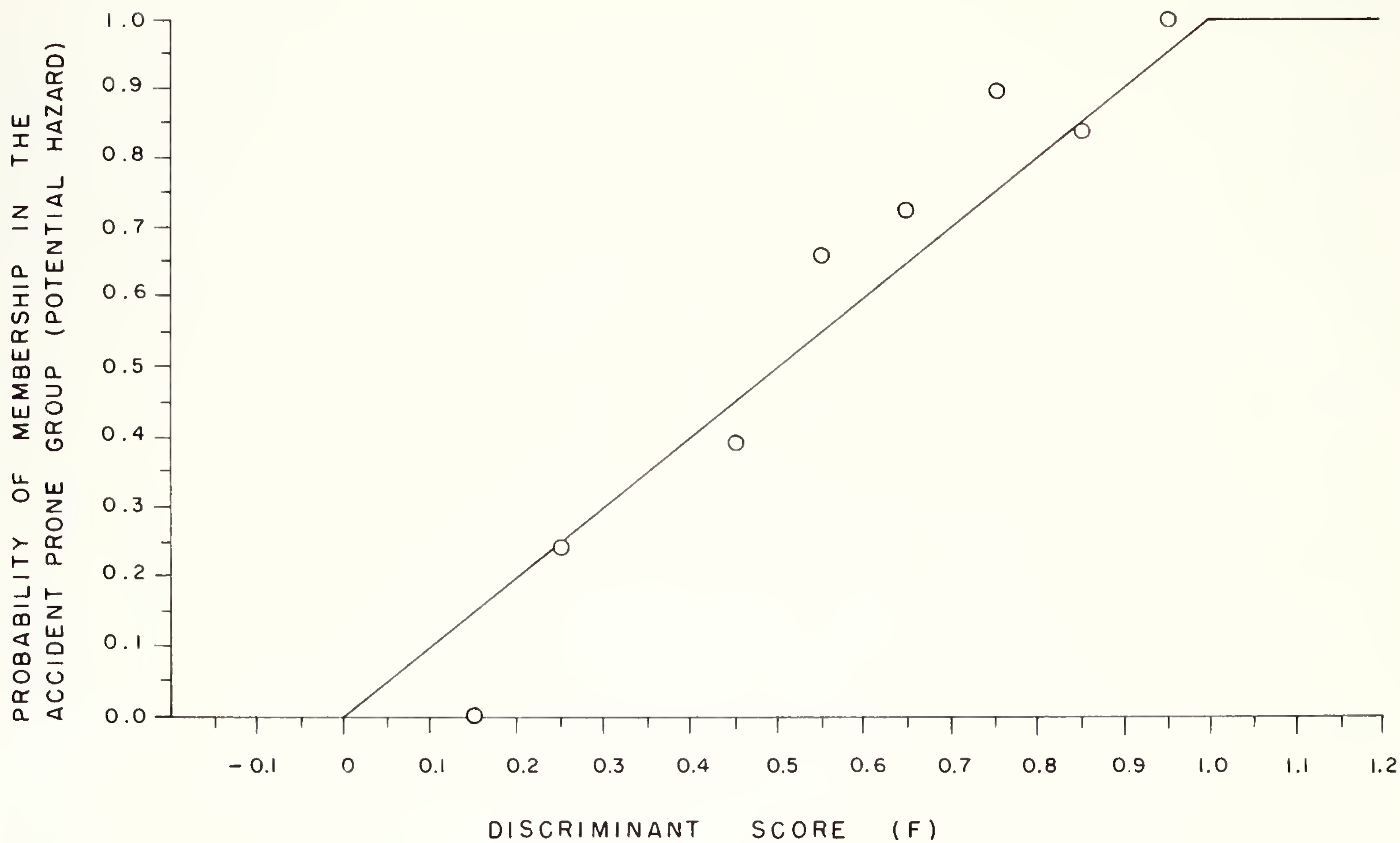


FIGURE 2. COMPARISON OF THE LINEAR ASSIGNMENT OF PROBABILITIES WITH THE ACTUAL PROBABILITIES FOR THE SAMPLE DATA

The selection of a maximum tolerable accident prone probability is dependent on several factors. First, consideration must be given to errors which result from misclassification. If a grade crossing is misclassified as a member of the non-accident prone group, the location is likely to be underprotected. On the other hand, if a crossing is misclassified in the accident prone group, the installation of a higher level of protection is likely to result in overprotection.

Secondly, the error which leads to underprotection may be considered more critical. By decreasing the maximum tolerable accident prone probability, the chance of underprotection is reduced. The errors of overprotection and underprotection are summarized in Table 5 for several maximum tolerable probabilities which are based on the sample data. The variations of error within the accident prone probability levels were caused by the scatter of the discriminant scores associated with each protective device.

Finally, a disadvantage of lowering the maximum tolerable accident prone probability is the increased number of grade crossings which require a higher level of protection. The greater protection requirements are directly related to the increased chance of overprotection and to the decreased chance of underprotection. If limited funds are available for the improvement of grade crossing protection, a decrease in the maximum tolerable probability also results in a reduction in the number of improvement projects which can be financed. This reduction is due to the substantially greater cost of the higher types of protective devices.

The final selection of a maximum tolerable accident prone probability must revert to subjective judgment of an acceptable and economically

TABLE 5

DISCRIMINANT MODEL ERROR PROBABILITIES AND SUCCESS PERCENTAGES AS A FUNCTION OF MAXIMUM TOLERABLE ACCIDENT PRONE PROBABILITY

Maximum Tolerable Accident Prone Probability	Type of Protection	Error Probabilities Underprotection (A)	Error Probabilities Overprotection (B)	Discriminant Model Success (C)
0.500	Painted crossbuck	0.23	0.30	74 %
	Reflectorized crossbuck	0.34	0.28	73 %
	Flasher	0.31	0.20	74 %
	Gate	0.45	0.13	75 %
0.375	Painted crossbuck	0.00	0.83	62 %
	Reflectorized crossbuck	0.00	0.85	61 %
	Flasher	0.11	0.47	73 %
	Gate	0.35	0.22	74 %
0.250	Painted crossbuck	0.00	0.98	55 %
	Reflectorized crossbuck	0.00	0.96	54 %
	Flasher	0.04	0.84	60 %
	Gate	0.25	0.35	68 %
0.125	Painted crossbuck	0.00	1.00	54 %
	Reflectorized crossbuck	0.00	1.00	52 %
	Flasher	0.00	0.98	56 %
	Gate	0.00	0.86	50 %

realistic error of underprotection. The curve shown as Figure 3 was developed to aid engineers and public officials in making this decision. The error or probability, of underprotection is plotted as a function of maximum tolerable accident prone probability. Utilization of the graph requires that an acceptable probability of underprotection be predetermined. This probability is then used to select the corresponding maximum tolerable accident prone probability indicated by the graph. The dashed line in the figure illustrates that there is a 10-percent chance of underprotection when the maximum tolerable accident prone probability is 41 percent.

Protection Nomograph

The estimation of potential hazard (probability of membership in the accident prone group) at any urban grade crossing is facilitated by the nomograph shown as Figure 4. In addition, the nomograph can be used to determine a minimum level of protection. This procedure requires that a maximum tolerable accident prone probability be selected from Figure 3. The minimum level of protection is then specified as the lowest level of protection which yields an accident prone probability less than the maximum tolerable value.

Because the sum of distractions and the line of sight ratio variables are referenced to one approach direction and one corner sight triangle, respectively, the nomograph must be evaluated for each grade crossing quadrant. The highest type of protection required in any quadrant is the recommended protective device for that particular grade crossing.

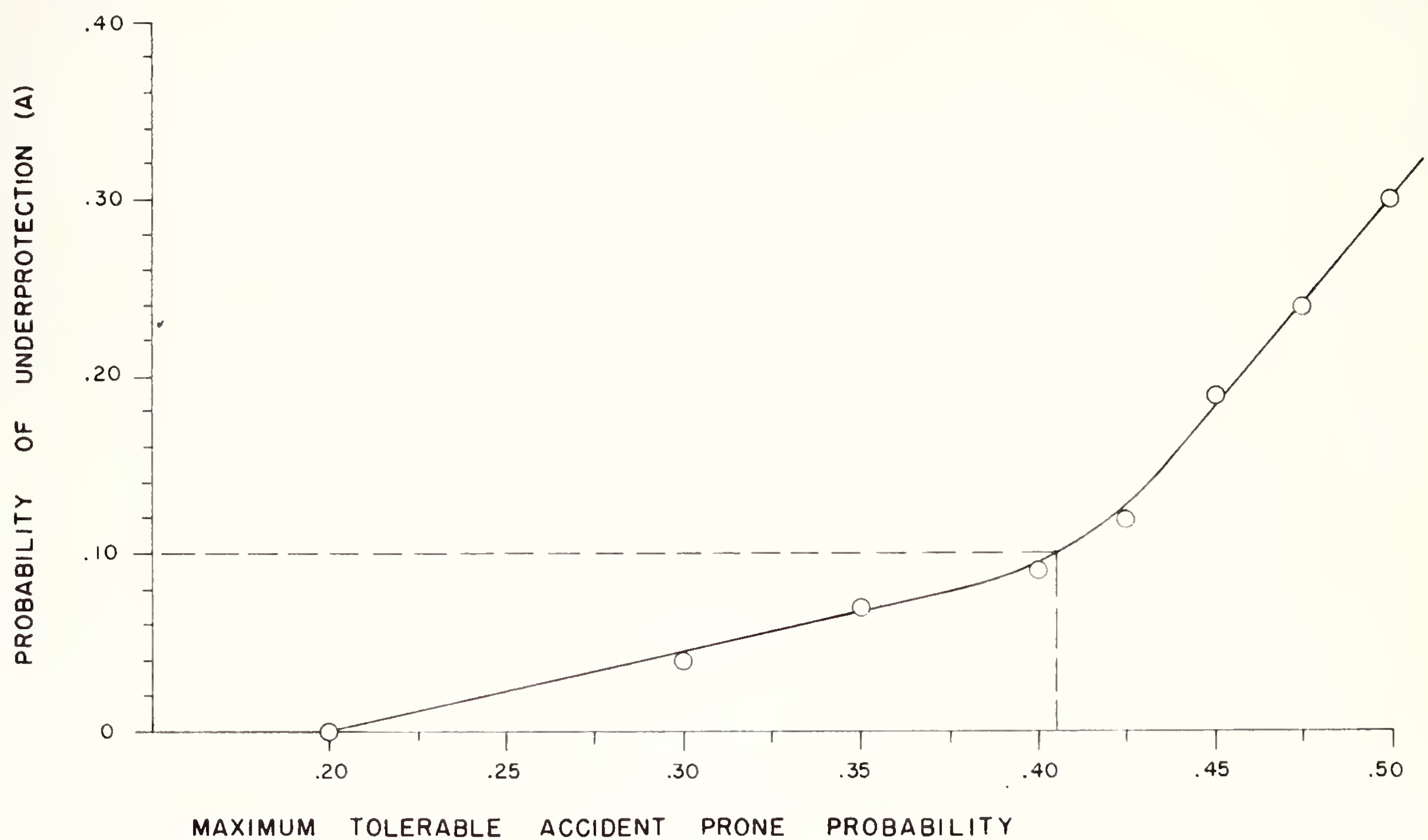
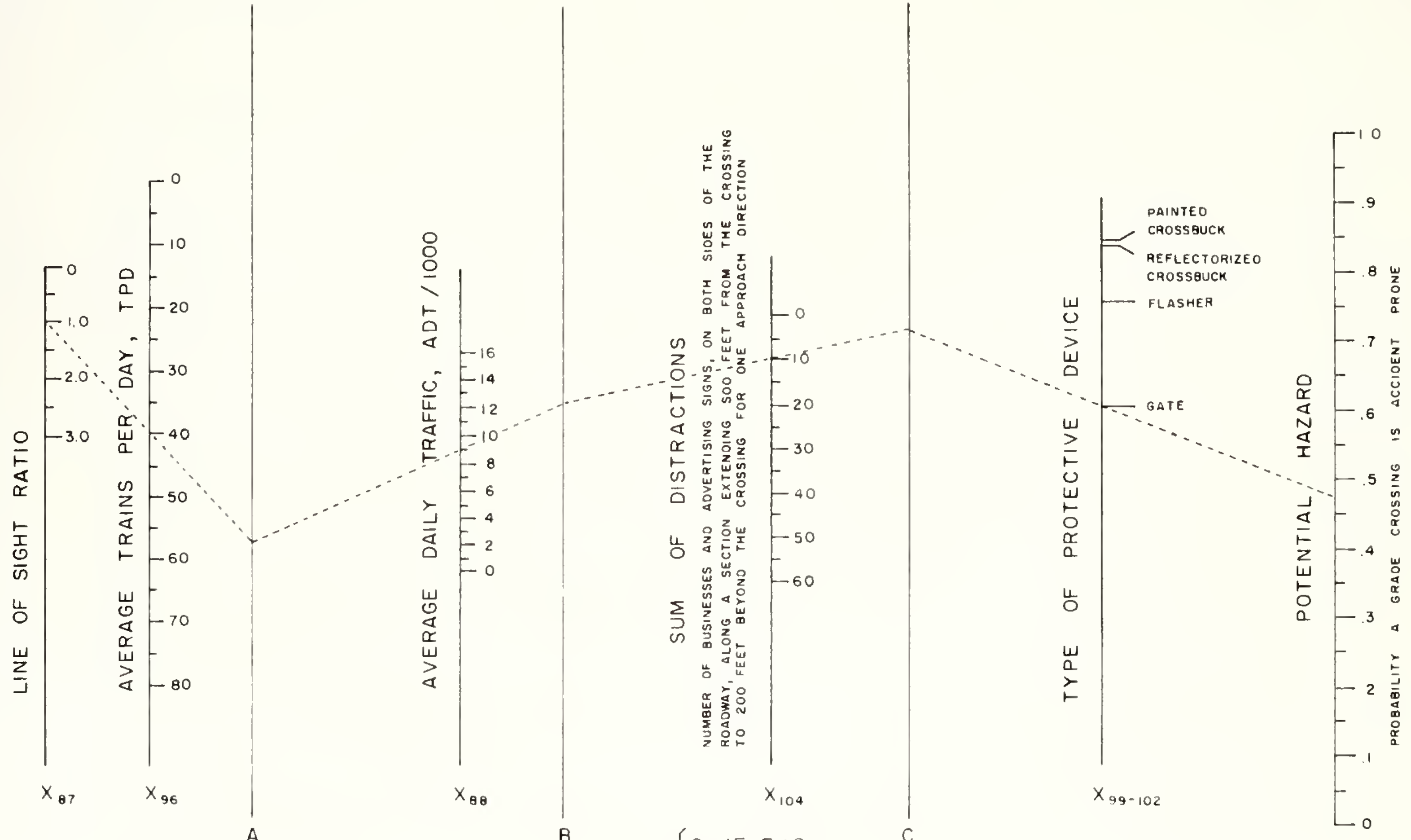


FIGURE 3. RELATION BETWEEN MAXIMUM TOLERABLE ACCIDENT PRONE PROBABILITY AND PROBABILITY OF UNDERPROTECTION



$$P_r = \begin{cases} 0, & \text{IF } F < 0 \\ F, & \text{IF } 0 \leq F \leq 1 \\ 1, & \text{IF } 1 < F \end{cases}$$

$$F = 0.412 - 0.033\,X_{87} + 0.024\,X_{88} + 0.007\,X_{96} - 0.021\,X_{100} - 0.195\,X_{101} - 0.525\,X_{102} + 0.013\,X_{104}$$

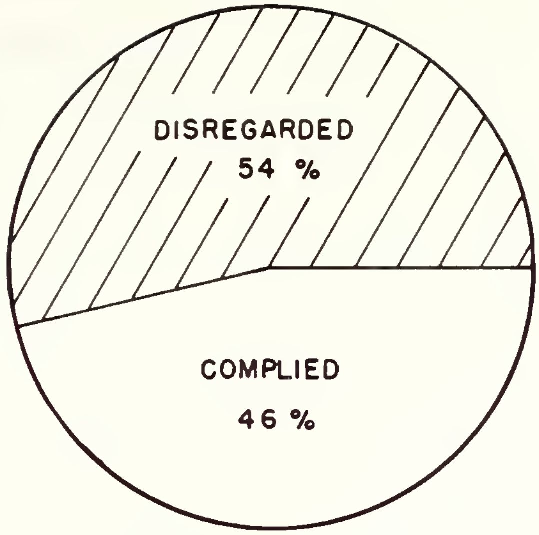
FIGURE 4. PROTECTION NOMOGRAPH - GRADE CROSSINGS LOCATED IN URBAN AREAS OF INDIANA

Protection Improvement Priorities

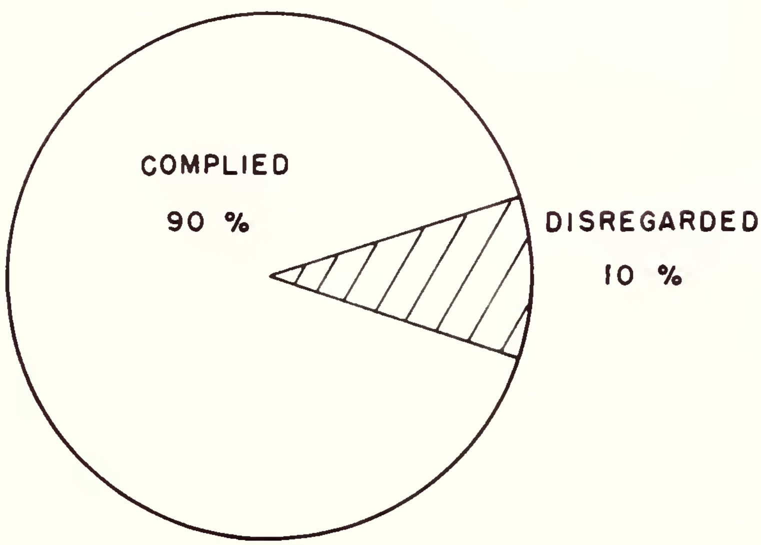
The discriminant model with linearly assigned probabilities also permits the establishment of protection improvement priorities based on potential hazard. Warranted grade crossing protection improvement projects can be ordered relative to their existing accident prone probabilities. The projects with the greatest potential hazard (probability of membership in the accident prone group) are then assigned the highest priorities for improvement.

Compliance Study

As evidenced by the results of the compliance study, driver attitudes and characteristics are germane to highway safety. Motorists approaching railroad-highway grade crossings which are protected with an automatic warning device often showed complete disregard for an actuated signal. The study sample was comprised of 153 observed motorists. A graphic representation of the statistical results is illustrated in Figure 5. Only 46-percent compliance was observed at flasher installations; however, there was 90-percent compliance at gate locations. The importance of these statistics is supported by the fact that in 27 percent of the accidents analyzed in this research investigation, the driver was reported to have disregarded an automatic warning device or a flagman. Thus, improvement of driver education and better enforcement of laws and regulations which apply to motor vehicle drivers at grade crossings appear to be warranted as a means of improving highway safety.



FLASHER PROTECTION



GATE PROTECTION

FIGURE 5. DRIVER OBSERVANCE OF RAILROAD – HIGHWAY GRADE CROSSING PROTECTIVE DEVICES

Application of the Study Results

The results of this research investigation can readily be applied by engineers who are responsible for the installation of protective devices at urban railroad-highway grade crossings. The following example illustrates the procedures for evaluating the potential hazard of a grade crossing, determining the minimum level of protection, and establishing protection improvement priorities.

For a hypothetical municipality, there are five railroad-highway grade crossings characterized by the data listed in Table 6. The potential hazard of each grade crossing quadrant was obtained by solving the protection nomograph shown as Figure 4.

The minimum level of protection desired at each grade crossing is a function of the maximum tolerable accident prone probability. For a 25-percent probability of underprotection, the maximum tolerable probability from Figure 3 is 0.48. This value represents the criterion for determining the minimum level of protection. The most hazardous quadrant at each grade crossing controls the selection of the required type of protection. The controlling quadrants are A2, B3, C2, D2, and E3 for the example problem. Because the potential hazard at quadrants B3 and C2 are less than or equal to the maximum tolerable value, the existing protective devices are considered adequate.

The minimum level of protection at the remaining three crossings is specified by using the protection nomograph to determine the lowest type of protective device which permits a potential hazard less than or equal to 0.48. The required protective devices for crossings A and E are a flasher and a gate, respectively. These devices replace the painted

TABLE 6

GRADE CROSSING DATA FOR EXAMPLE PROBLEM

Grade Crossing	Quadrant	ADT	TPD	Type of Protection	Sum of Distractions	Line of Sight Ratio	Potential Hazard
A		1,200	14	Painted crossbuck			
	1				5	0.67	0.58
	2				5	0.34	0.59
	3				3	1.38	0.53
	4				3	0.82	0.55
B		1,800	10	Flasher			
	1				8	0.61	0.41
	2				8	1.03	0.40
	3				13	0.70	0.48
	4				13	0.79	0.47
C		400	6	Reflectorized crossbuck			
	1				2	1.84	0.41
	2				2	1.28	0.43
	3				0	0.97	0.41
	4				0	1.06	0.41
D		5,200	24	Gate			
	1				31	0.36	0.57
	2				31	0.10	0.58
	3				19	0.12	0.43
	4				19	0.57	0.41

TABLE 6 (cont'd.)

Grade Crossing	Quadrant	ADT	TPD	Type of Protection	Sum of Distractions	Line of Sight Ratio	Potential Hazard
E		2,300	40	Flasher			
	1				5	0.10	0.62
	2				5	1.01	0.58
	3				8	0.21	0.65
	4				8	0.48	0.64

crossbuck at A and the flasher at E, and afford the following reductions in potential hazard for the controlling quadrants:

	Existing	After Improvement
A2	0.59	0.40
E3	0.65	0.32

Because grade crossing D is presently protected with the highest type of protective device, an automatic gate, a grade separation may be warranted. However, the application of traffic engineering principles may reduce the chance of driver error in the vicinity of the grade crossing, and thus permit a less costly improvement.

Protection improvement priorities can be established on the basis of existing potential hazard. For the 25-percent probability of underprotection, grade crossing E has a higher priority than grade crossing A.

SUMMARY OF RESULTS AND CONCLUSIONS

The following results and conclusions summarize the findings of this research investigation of safety at urban railroad-highway grade crossings in the State of Indiana.

1. Most accidents involved male drivers who resided in the city and county in which the accident occurred.
2. Approximately one out of ten accident drivers had been drinking.
3. Motorists apparently were unaware of the presence of a train or willfully disregarded an automatic warning device in 65 percent of the accidents.
4. About one out of every two grade crossing accidents resulted in a personal injury or fatality.
5. Trucks represented 12 percent of the accident vehicles. Few vehicles evidenced contributing mechanical defects, although 21 percent skidded or were out of control at the time of impact.
6. Three-quarters of the accidents occurred during clear weather, and almost one-half took place during the hours of darkness.
7. Pavements were wet or were covered with ice or snow in 40 percent of the collisions.
8. The development of a discriminant model with linearly assigned probabilities permitted potential hazard to be expressed as the probability that a grade crossing can be considered accident prone.

[illegible] The [illegible]

reuse [illegible]

in th[illegible]

6. [illegible]

the [illegible]

7. Fa[illegible]

cont[illegible]

8. The deviation [illegible]

probabilities [illegible]

probability that [illegible]

proces[illegible]

9. By definition, the occurrence of an accident during a two-year period and the non-occurrence of an accident for a minimum period of five years was considered to be representative of accident prone and non-accident prone grade crossings, respectively. The discriminant model related potential hazard to type of protective device, average daily highway traffic, average daily train traffic, a measure of effective sight distance, and a measure of roadside distractions.
10. The linear discriminant model was 74-percent successful in assigning the sample grade crossings into accident and non-accident groupings. Therefore, the model was considered to be a reliable predictor of potential hazard.
11. The suggested procedure for establishing a minimum level of protection was to determine the minimum protection requirement for each grade crossing quadrant relative to a selected maximum tolerable accident prone probability. The recommended protective device for that particular grade crossing was the highest type of protection required in any quadrant.
12. A technique for establishing protection improvement priorities was based on a numerical ranking of the existing accident prone probabilities.
13. A nomograph shown as Figure 4 was developed to facilitate the determination of minimum levels of protection and the establishment of protection improvement priorities.

14. The relative effectiveness of the protective devices were measured by the coefficients of the protective device variables appearing in the discriminant model. These coefficients are indicative of the reductions in potential hazard relative to the level of protection offered by a painted crossbuck:

a.	Painted crossbuck	0.000
b.	Reflectorized crossbuck	0.021
c.	Flasher	0.195
d.	Gate	0.525

15. The results of a compliance study at urban grade crossings protected with an automatic protective device indicated approximately 46-percent observance of actuated flashers and 90-percent observance of actuated gates.

34. The relative effectiveness of [illegible] positive [illegible] were not [illegible]

SUGGESTIONS FOR FURTHER RESEARCH

This evaluation of safety at urban railroad-highway grade crossings indicated several possibilities for further research. The following areas are suggested for additional study.

1. The methodologies used in this investigation should be applied and analyzed for railroad-highway grade crossings located in rural areas as well as other urban areas.
2. On-the-spot investigation of grade crossing accidents provide an invaluable opportunity for detailed analysis of driver behavior and other influencing circumstances. Driver motivations and characteristics may offer a significant insight into the causes of motor vehicle-train collisions.
3. Methods of improving driver awareness and compliance of protective devices merits research investigation. New or over-sized signal devices may be warranted on the basis of improved safety or better driver compliance.

BIBLIOGRAPHY

BIBLIOGRAPHY

1. American Association of State Highway Officials, A Policy on Geometric Design of Rural Highways, Washington, D. C., 1954.

2. American Railway Engineering Association, Engineering Division, Association of American Railroads, Manual of Recommended Practice, Chapter 9, Parts 1 to 5, Washington, D. C., 1962.

3. Armour Research Foundation, "Analysis of Railroad Crossing and Accident Data," ARF Project E 641 Final Report, Chicago, Illinois, 1958.

4. Armour Research Foundation, "Analysis of Railroad Crossing and Accident Data for the State of Ohio During the Ten Year Period, 1949 Through 1958," ARF Project E 672 Final Report, Chicago, Illinois, 1961.

5. Association of American Railroads, American Railway Signaling Principles and Practices, Chicago, Illinois, 1962.

6. Association of American Railroads, Highway News Letter No. 63-1, Washington, D. C., 1963.

7. Association of American Railroads, "Recommended Standards and Practices for Railroad-Highway Grade Crossing Protection," Bulletin No. 5, Washington, D. C., 1955.

8. Automotive Safety Foundation, Traffic Control and Roadway Elements, Their Relationship to Highway Safety, U. S. Bureau of Public Roads, Washington, D. C., 1963.

9. Bezkorovainy, G. and Holsinger, R. G., "The Use of Stop Signs at Railroad Crossings," Traffic Engineering Department, City of Lincoln, Nebraska, 1966.

10. Chubb, T. M., "Railroad Crossing Protection: Priorities at Grade," Proceedings, The Twelfth California Street and Highway Conference, The Institute of Traffic and Transportation Engineering, University of California, Berkeley, California, 1960.

11. Cooley, W. W. and Lohnes, P. R., Multivariate Procedures for the Behavioral Sciences, John Wiley & Sons, Inc., New York, 1962.

12. Crecink, W. J., "Evaluating Hazards at Railway Grade Crossings," Proceedings, Highway Research Board, Washington, D. C., 1948.

BIBLIOGRAPHY (cont'd.)

13. Hays, Joseph H., "The ICC Report on Prevention of Grade-Crossing Collisions," Annual Meeting of American Railway Engineering Association, Chicago, Illinois, March 23, 1965.

14. Hays, Joseph H., "Can Government Curb Grade Crossing Accidents?", Traffic Safety, Chicago, Illinois, April 1964.

15. Hedley, W. J., "The Achievement of Grade Crossing Protection," Proceedings, American Railway Engineering Association, Washington, D. C. 1949.

16. Institute of Traffic Engineers, Traffic Engineering Handbook, Washington, D. C., 1965.

17. Indiana State Police, Indiana Traffic Deaths 1965, Indianapolis, Indiana, 1966.

18. Interstate Commerce Commission, "Rail-Highway Grade-Crossing Accidents," Statement No. 6305, Washington, D. C., 1963.

19. Interstate Commerce Commission, "Issues Report on Highway-Rail Accident Study," Traffic Safety, Chicago, Illinois, April 1964.

20. Interstate Commerce Commission, "Prevention of Rail-Highway Grade Crossing Accidents Involving Trains and Motor Vehicles," Docket No. 33440, Washington, D. C., 1964.

21. Iowa State Commerce Commission, Summary, Highway Railroad Grade Crossing Accidents in the State of Iowa, Des Moines, Iowa, 1958.

22. Iowa State Highway Commission, "Deficiency Rating of Iowa Primary Highway-Railroad Crossings," Ames, Iowa, 1957.

23. Johnson, Arnold A., "Maximum Safe Vehicle Speeds at Railroad Grade Crossings," Traffic Engineering, Washington, D. C. June 1958.

24. Manual of Geometric Design Standards for Canadian Roads and Streets, Geometric Design Committee, Canadian Good Roads Association, Ottawa, Canada, 1963.

25. Marks, Harold, "Railroad Crossing Protection: How Much Is Justified?" Proceedings, The Twelfth California Street and Highway Conference, The Institute of Traffic and Transportation Engineering, University of California, Berkeley, California, 1960.

26. McEachern, Cooper, "A Study of Railroad Grade Crossing Protection in Houston," Proceedings, Institute of Traffic Engineers, Washington, D. C., 1960.

APPENDIX A

LINE OF SIGHT RATIO DERIVATION AND CURVES

BIBLIOGRAPHY (cont'd.)

27. McLaughlin, W. A., "Highway-Railway Grade Crossing Treatments," Technical Publication No. 13, Canadian Good Roads Association, Ottawa, Canada, 1960.

28. Michigan Railroads Association, "Study of Michigan Crossing Accidents," Detroit, Michigan, 1961.

29. National Committee on Uniform Traffic Laws and Ordinances, Uniform Vehicle Code, Washington, D. C. 1962.

30. National Safety Council, Accident Facts, Chicago, Illinois, 1965.

31. Newnan, Donald G., "An Economic Analysis of Railway Grade Crossings on the California State Highway System," Report EEP-16, Institute in Engineering-Economic Systems, Stanford University, June 1965.

32. Ohio Legislative Service Commission, "Grade Crossings in Ohio," Staff Research Report No. 23, Columbus, Ohio, 1957.

33. Oregon State Highway Department, "Relative Hazards at Railroad Grade Crossings on State and Federal Aid Highway Systems," Salem, Oregon, 1956.

34. Peabody, L. E. and Dimmick, T. B., "Accident Hazards at Grade Crossings," Public Roads Vol. 22, No. 6, Washington, D. C. August 1941.

35. Raymond, W. G., Riggs, H. E., and Sadler, W. C., Elements of Railroad Engineering, John Wiley and Sons, Inc., New York, 1947.

36. Schultz, T. G., "Evaluation of Safety at Railroad-Highway Grade Crossings," Final Report No. 9, Joint Highway Research Project, Purdue University, Lafayette, Indiana, 1965.

37. The Port of New York Authority Engineering Department, Research and Development Division, "Some Techniques for the Evaluation of Ground Service to Air Travelers," Report 63-5, October 1963.

38. Traffic Institute, "Safety Program for Railroad Grade Crossings," Traffic Digest and Review, Vol. 12, No. 9, Northwestern University, September 1964.

39. United States Bureau of Public Roads, "Policy and Procedure Memorandum 21-10," Washington, D. C. 1958.

40. United States Bureau of Public Roads, Manual on Uniform Traffic Control Devices for Streets and Highways, U. S. Department of Commerce, Washington, D. C., 1961.

BIBLIOGRAPHY (cont'd.)

41. Warner, Stanley Leon, Stochastic Choice of Mode in Urban Travel: A Study in Binary Choice, The Transportation Center at Northwestern University, Northwestern University Press, 1962.

42. Woods, Kenneth B., Ed., Highway Engineering Handbook, McGraw-Hill Book Company, New York, 1960.

43. Wyatt, George H., Testimony, Interstate Commerce Commission, Docket No. 33440, Washington, D. C. 1964.

APPENDIX A

Line of Sight Ratio Derivation and Curves

This appendix contains the derivation of the line of sight ratio variable, information for obtaining the necessary field measurements, and curves for determining the numerical value of the line of sight ratio.

The derivation of the line of sight ratio is based on the following definitions:

V_c = assumed vehicle speed for a given posted speed limit - mph,

SSD = minimum stopping sight distance - feet,

D_b = braking distance - feet,

t_1 = perception-reaction time - seconds,

t_2 = time required for a driver to bring his vehicle to a stopped position within the minimum stopping sight distance - seconds,

V_t = speed of fastest train - mph,

D_t = distance traveled by fastest train - feet,

φ = angle of intersection - degrees,

θ = actual corner sight angle - degrees, and

Δ = minimum desirable corner sight angle - degrees.

The geometry of the line of sight triangle is shown in Figure 6. Thus, for a generalized configuration, the time and distance relationships are:

$$t_2 = t_1 + \frac{2\ D_b}{1.47\ V_c}$$

$$= 2.5 + \frac{2\ D_b}{1.47\ V_c}\ , \text{ and}$$

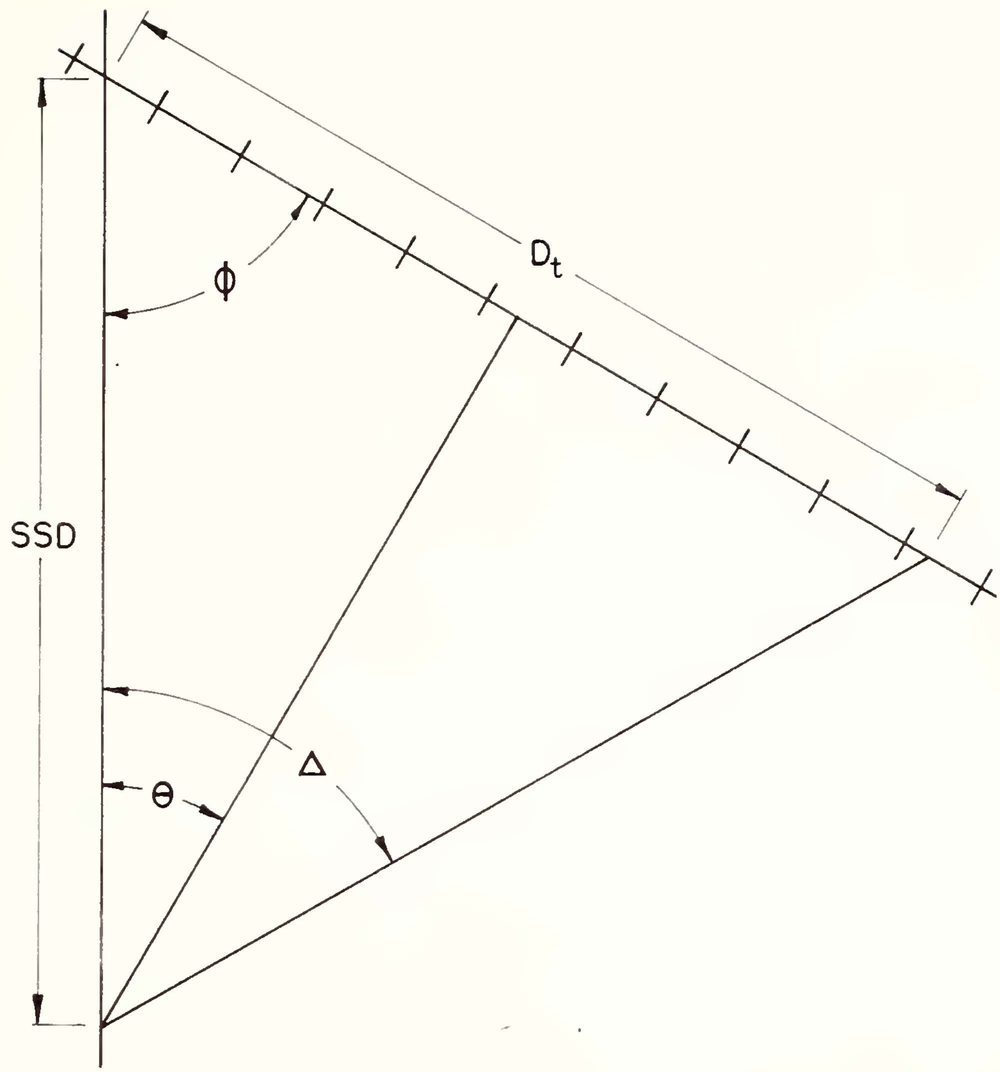


FIGURE 6. GEOMETRY OF THE CORNER SIGHT TRIANGLE

$$D_t = 1.47\ V_t\ t_2$$

Therefore, by the Sine Law, the minimum desirable corner sight angle is expressed as:

$$\frac{\sin \Delta}{D_t} = \frac{\sin (180 - \omega - \Delta)}{SSD}$$

The determination of Δ requires a trial and error solution of the above expression. The line of sight ratio is then equivalent to the actual corner sight angle divided by the minimum desirable corner sight angle.

Computation of the line of sight ratio is facilitated by the curves shown as Figures 7 through 12. These figures also permit a graphical solution of the minimum desirable corner sight angle. The development of the curves was based on the above derivation and the relationships listed in Table 7 (1). The table also provides the minimum stopping sight distances necessary for field measurement of the actual corner sight angle.

The procedure for determining the line of sight ratio for any grade crossing quadrant is illustrated by the following example:

Given: 20-mph posted speed limit; 90-deg intersection angle; and speed of fastest train = 50 mph.

1. The minimum stopping sight distance of 97 ft is obtained from Table 7.
2. At a distance of 97 ft from the grade crossing, the maximum corner sight angle is measured for the given quadrant. This angle represents the actual corner sight angle, θ.
3. On Figure 7, a horizontal line is extended from the fastest train speed value of 50 mph to the curve representing an angle of intersection of 90 deg.

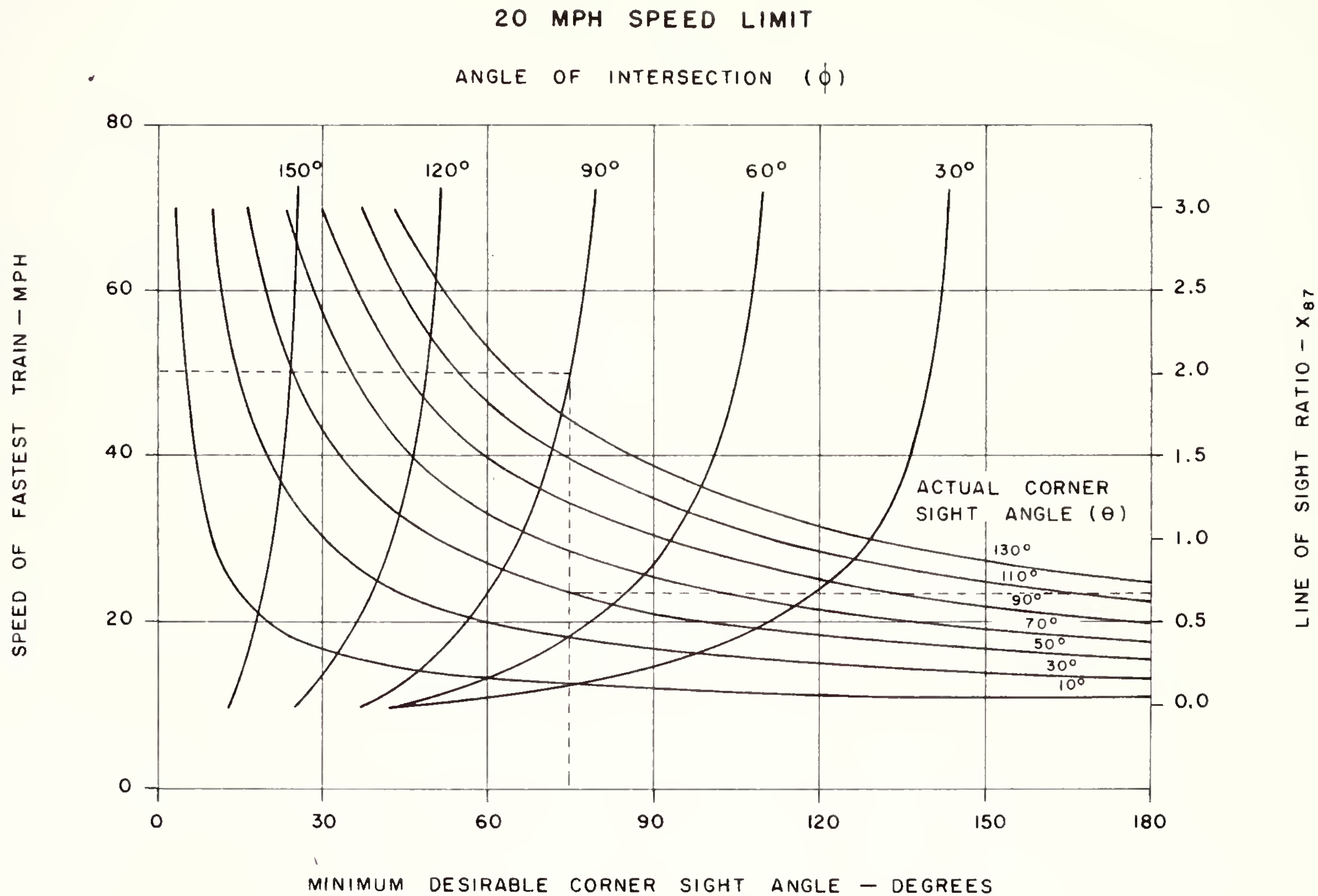


FIGURE 7. LINE OF SIGHT RATIO CURVES

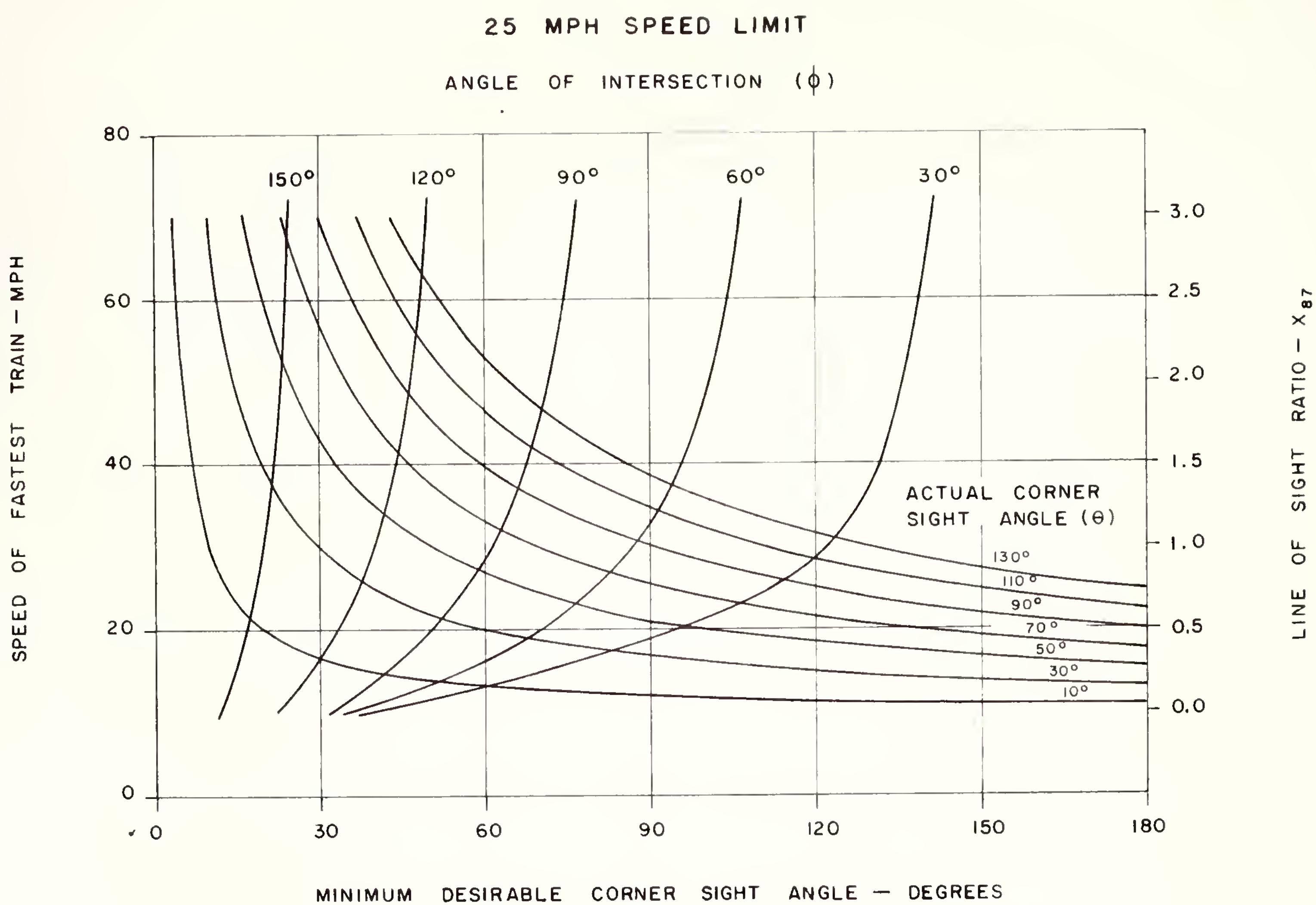


FIGURE 8. LINE OF SIGHT RATIO CURVES

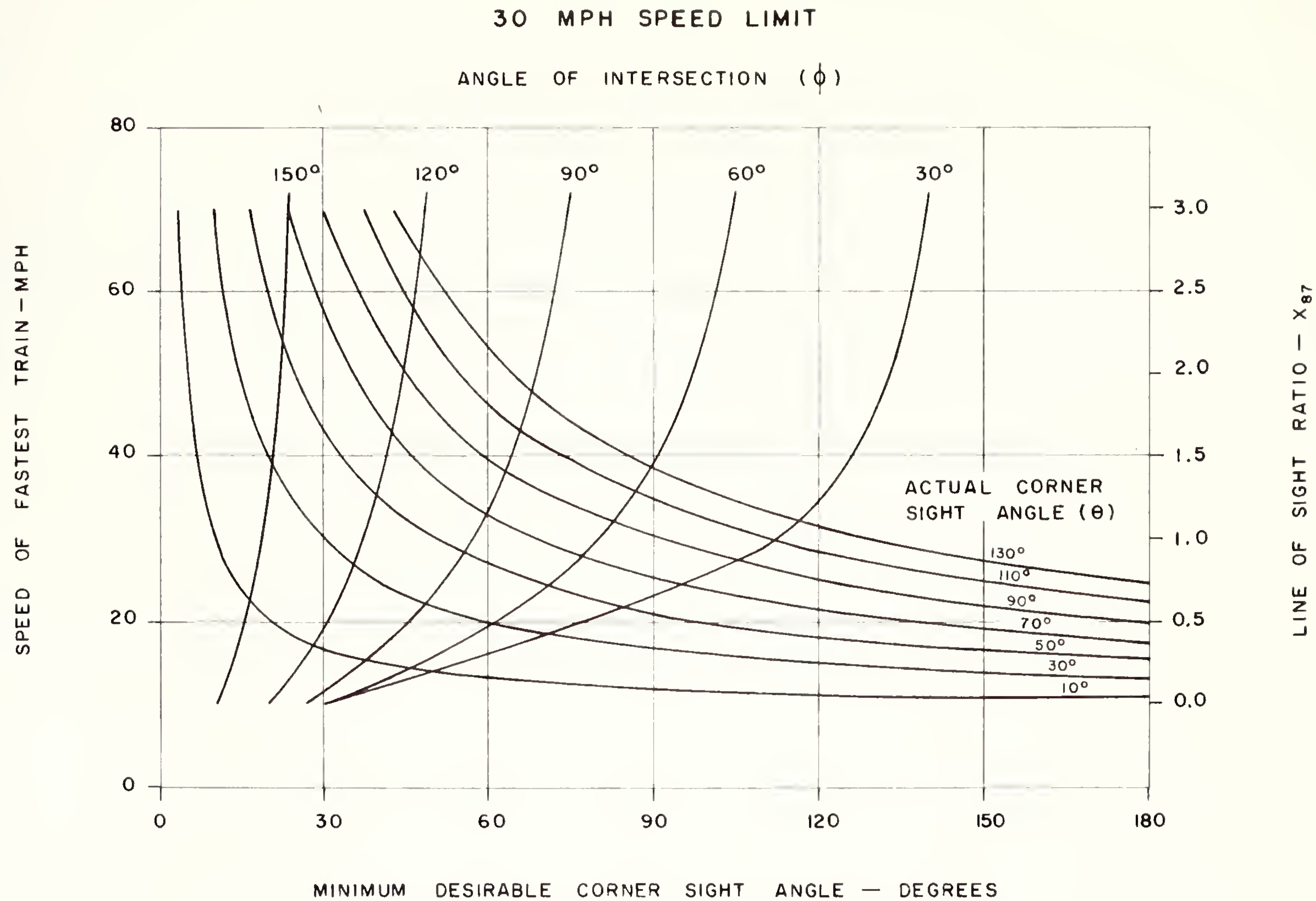


FIGURE 9. LINE OF SIGHT RATIO CURVES

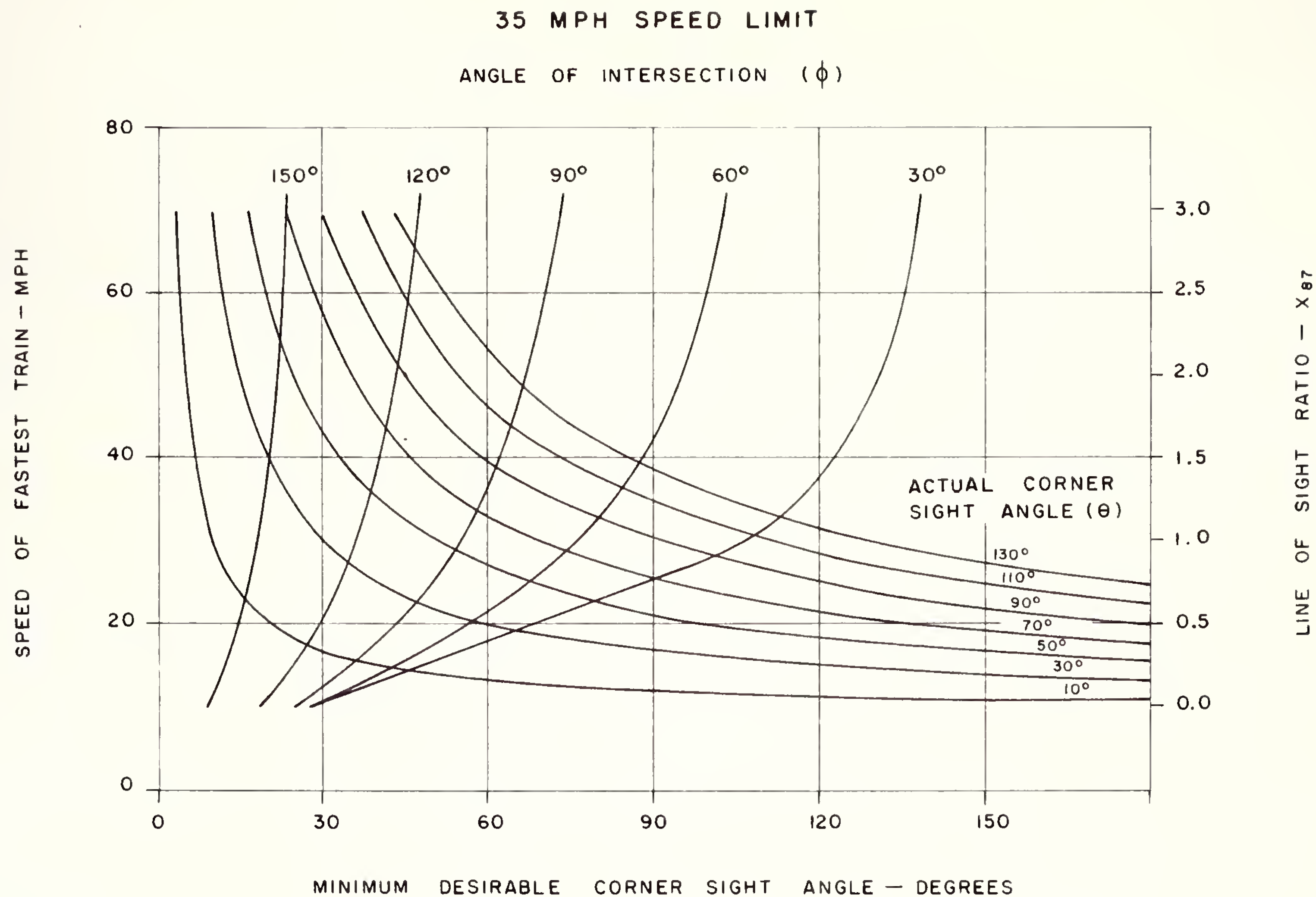


FIGURE 10. LINE OF SIGHT RATIO CURVES

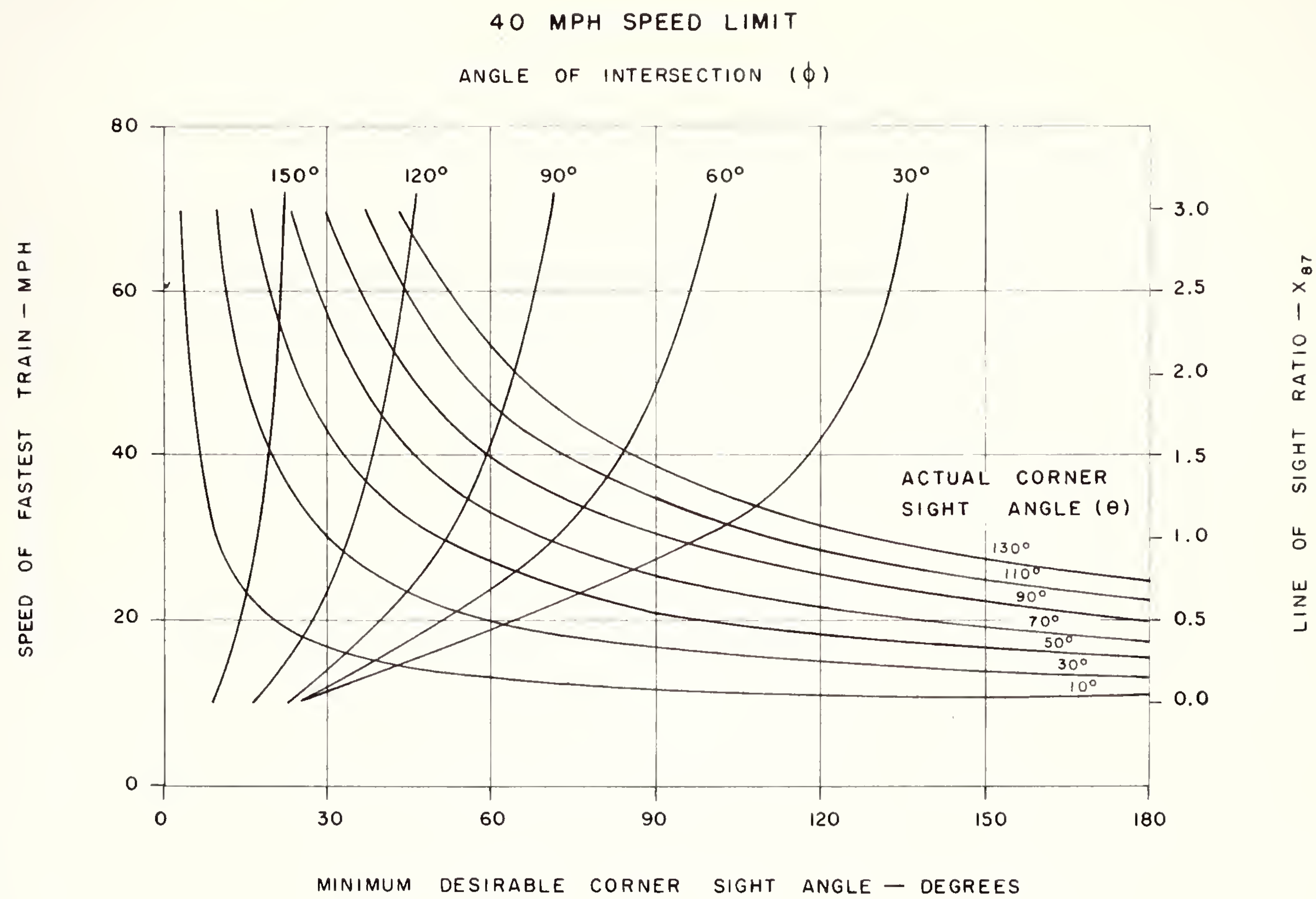


FIGURE 11. LINE OF SIGHT RATIO CURVES

45 MPH SPEED LIMIT

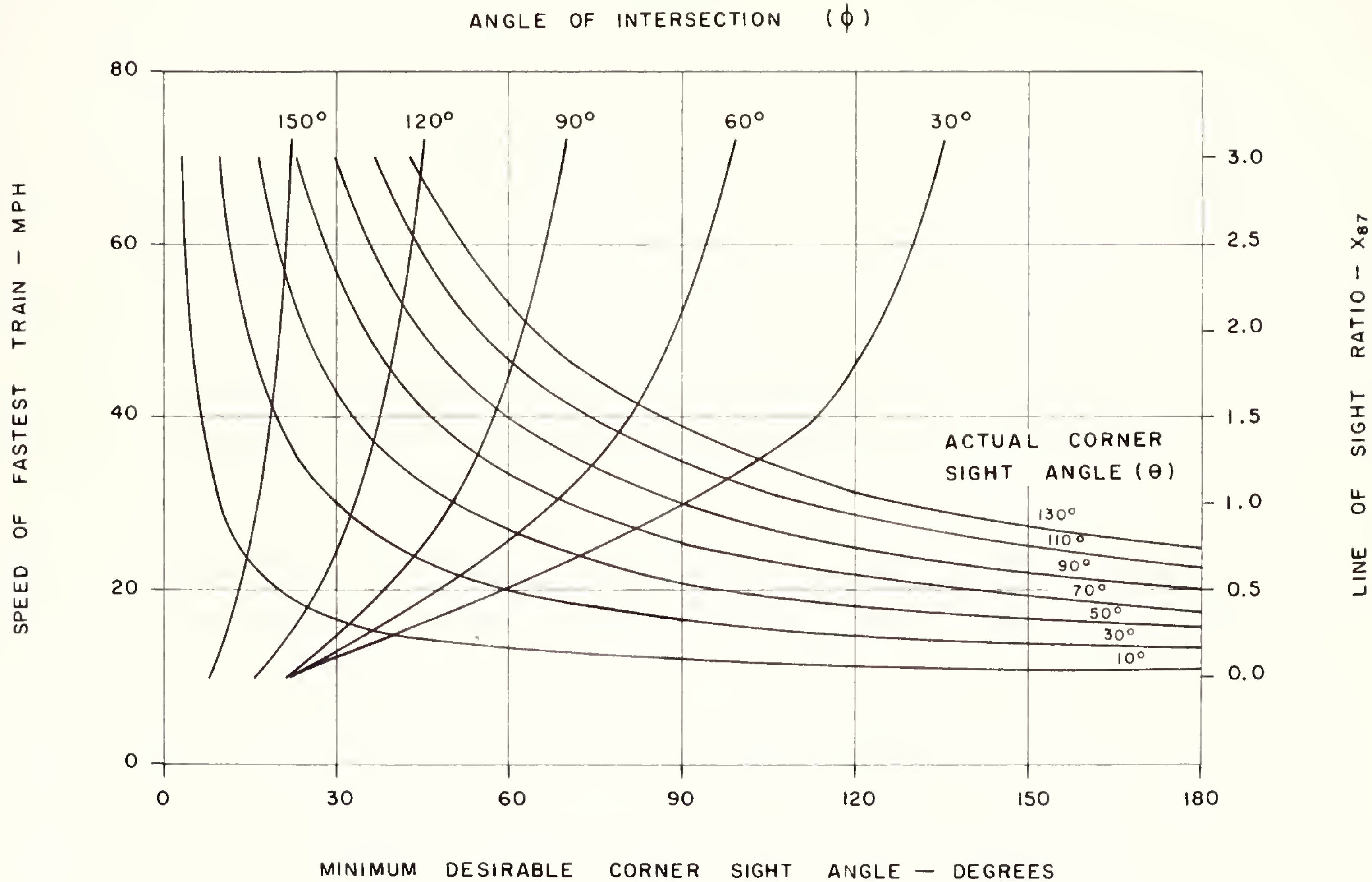


FIGURE 12. LINE OF SIGHT RATIO CURVES

APPENDIX B

SAMPLE DATA SHEET

TABLE 7

MINIMUM STOPPING SIGHT DISTANCE RELATIONSHIPS

Posted Speed Limit	V_c (mph)	D_b (ft)	SSD (ft)
20	18	31	97
25	23	51	136
30	28	73	176
35	32	106	223
40	36	131	263
45	40	168	314

4. From this point, a vertical line is extended to the minimum desirable corner sight angle, 75 deg.
5. From the intersection of the vertical line and the curve representing the actual corner sight angle, a horizontal line is extended to the line of sight ratio axis.
6. This intersection point is the line of sight ratio for the given conditions.
7. For an actual corner sight angle of 50 deg, the line of sight ratio is 0.67.

APPENDIX B

FIELD DATA SHEET

Crossing Number ________ Accident Number ________ Date ________

County ________ City ________ Street ________ RR ________

Protection	Good	Poor
Painted Crossbuck	___	___
Reflectorized Crossbuck	___	___
Bells		___
Flasher		___
Flasher and Bells		___
Gate and Flasher		___
Gate, Flasher, and Bells		___
Flagman		___
Stop Sign		___
Traffic Signal		___
Coordinated Traffic Signal		___
Other ________		

Roadway Features
- Speed Limit ___
- RR Advance Warning Sign ___
- RR Pavement Marking ___
- Street Operation:
  - Two-way ___
  - No. of Lanes ___
  - Local ___
  - Collector ___
  - Arterial ___
- Painted Centerline ___
- Curb and Gutter ___
- Curb Parking ___
- Bus Stop ___
- Illuminated Roadway ___
- Pavement Width ___
- Pavement Type:
  - P.C.C. ___
  - Asphalt ___
  - Gravel ___
  - Other ________

Railroad Features
- No. of Tracks ___
- Mainline Tracks ___
- Rough Crossing Surface ___
- RR Yards ___
- Passenger Station ___
- Tracks in Middle of Street ___

Roadside Features
- Approach to Crossing:
  - No. of Businesses ___
  - No. of Signs ___
  - No. of Dwellings ___
  - No. of Access Points ___
  - No. of Streets ___
  - No. of Loading Zones ___
- Beyond Crossing:
  - No. of Businesses ___
  - No. of Signs ___
  - No. of Dwellings ___
  - No. of Access Points ___
  - No. of Streets ___
  - No. of Loading Zones ___
- Minor Obstructions ___
- Locality:
  - Residential ___
  - Business ___
  - Industrial ___
- High Volume Roadway
  - Parallel to RR ___

Traffic Volume
- 1-hr Count ___
- Day ___
- Time ___

Remarks

Line of Sight

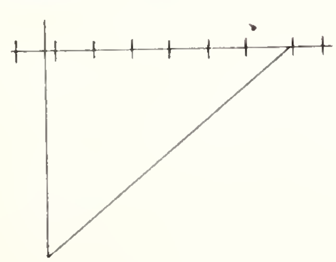


FIGURE 13. Sample Data Sheet

APPENDIX C

TRAFFIC VOLUME EXPANSION AND ADJUSTMENT FACTORS

APPENDIX C

Traffic Volume Expansion and Adjustment Factors

The data tabulated in the following tables were used to obtain the average daily traffic, ADT, from an 1-hr manual count. The ADT is expressed as:

$$ADT = \frac{V}{(F_1 \times F_2 \times F_3)}$$

where V = traffic volume during any 1-hr period,

F_1 = hourly traffic volume expansion factor,

F_2 = daily traffic volume adjustment factor, and

F_3 = monthly traffic volume adjustment factor.

TABLE 8

HOURLY TRAFFIC VOLUME EXPANSION FACTORS
FOR URBAN STREETS IN THE STATE OF INDIANA

Hour	Expansion Factor
12- 1 A.M.	1.6
1- 2	0.9
2- 3	0.6
3- 4	0.5
4- 5	0.5
5- 6	0.9
6- 7	4.4
7- 8	4.6
8- 9	4.7
9-10	4.5
10-11	4.7
11-12	5.8
12- 1 P.M.	7.1
1- 2	5.4
2- 3	5.5
3- 4	6.9
4- 5	8.4
5- 6	7.4
6- 7	5.5
7- 8	5.7
8- 9	4.6
9-10	4.0

TABLE 8 (cont'd.)

Hour	Expansion Factor
10-11	3.4
11-12	2.4

TABLE 9

DAILY TRAFFIC VOLUME ADJUSTMENT FACTORS
FOR URBAN STREETS IN THE STATE OF INDIANA

Day	Adjustment Factor
Monday	1.005
Tuesday	0.963
Wednesday	0.980
Thursday	0.972
Friday	1.080
Saturday	1.083
Sunday	0.961

TABLE 10

MONTHLY TRAFFIC VOLUME ADJUSTMENT FACTORS
FOR THE STATE OF INDIANA

Month	Adjustment Factor
January	0.741
February	0.817
March	0.843
April	0.942
May	1.058
June	1.118
July	1.199
August	1.248
September	1.186
October	1.081
November	0.964
December	0.851

APPENDIX D

MEANS AND STANDARD DEVIATIONS OF THE STUDY VARIABLES

APPENDIX D

TABLE 11

MEANS AND STANDARD DEVIATIONS OF THE STUDY VARIABLES

Variable	Mean	Standard Deviation
1	36.9181	15.5693
2	0.7829	0.4130
3	0.3452	0.4763
4	0.1530	0.3607
5	0.0391	0.1943
6	0.1103	0.3138
7	0.8754	0.3308
8	5.0961	3.7352
9	0.0249	0.1561
10	0.0961	0.2952
11	0.3915	0.4889
12	8.7139	18.4652
13	*	*
14	*	*
15	*	*
16	0.2028	0.4028
17	0.1957	0.3975
18	0.2135	0.4105
19	0.4520	0.4986
20	0.7580	0.4291
21	0.0676	0.2515
22	0.3772	0.4856
23	0.2740	0.4468
24	3.4555	0.4989
25	0.1138	0.3179
26	0.0821	0.2748
27	0.0951	0.2937
28	0.0131	0.1136
29	0.0224	0.1481
30	0.0112	0.1053

TABLE 11 (cont'd.)

Variable	Mean	Standard Deviation
31	0.2966	0.4572
32	0.1623	0.3691
33	0.0280	0.1651
34	0.0690	0.2537
35	0.0149	0.1214
36	0.0187	0.1354
37	0.0392	0.1942
38	0.0205	0.1419
39	0.0392	0.1942
40	26.0914	4.2551
41	0.2108	0.4083
42	0.0560	0.2301
43	0.9384	0.2406
44	2.1772	0.5930
45	0.4496	0.4979
46	0.3563	0.4794
47	0.1940	0.3958
48	0.3601	0.4805
49	0.5280	0.4997
50	0.6138	0.4873
51	0.0354	0.1851
52	0.0410	0.1986
53	0.1362	0.3487
54	29.7313	10.4344
55	13.8425	4.2414
56	0.1157	0.3201
57	0.8433	0.3639
58	0.0243	0.1540
59	0.0168	0.1286
60	2.1996	1.4974
61	1.3358	0.7631

TABLE 11 (cont'd.)

Variable	Mean	Standard Deviation
62	0.6250	0.4846
63	0.1007	0.3013
64	0.0410	0.1986
65	0.0205	0.1419
66	0.0466	0.2111
67	0.0840	0.2776
68	2.6474	3.1618
69	2.4067	3.4417
70	4.8731	4.9520
71	5.6735	2.8665
72	1.5840	1.2472
73	0.4216	0.7371
74	1.4459	1.6214
75	1.2854	2.0911
76	1.7966	2.2799
77	2.8713	1.6350
78	0.8041	0.8366
79	0.2892	0.5368
80	0.4254	0.4949
81	0.3228	0.4680
82	0.2519	0.4345
83	0.4534	0.4983
84	0.0690	0.2537
85	102.8393	155.3804
86	90.6660	27.5946
87	1.2192	1.1519
88	3.6422	4.7136
89	16.6082	22.1628
90	23.8582	15.3811
91	5.8321	5.1346
92	22.4384	15.2291

TABLE 11 (cont'd.)

Variable	Mean	Standard Deviation
93	3.0056	5.3723
94	9.5522	10.6801
95	6.5896	17.7887
96	19.1474	23.6463
97	30.9235	32.7197
98	27.3302	18.2548
99	0.1959	0.3973
100	0.1082	0.3109
101	0.4590	0.4988
102	0.1119	0.3156
103	4.0933	4.1579
104	7.7854	8.5496
105	14.4552	8.8905
106	23.0000	11.1819
107	16.8433	9.4151
108	23.7108	11.3104
109	82.9025	173.3924

* Incomplete data